The Health of Forested Riparian Buffers Following Adjacent Upland Forest Harvesting

And

The Establishment of Long-term Forest Bio-monitoring Plots in the Boreal Forest of Eastern Manitoba and in Urban Forests of Winnipeg, Manitoba

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SUMMARY

Long-term forest vegetation monitoring plots were established in the summer of 2007 in the boreal forest of eastern Manitoba and also in the Assiniboine Forest within the City of Winnipeg. The establishment of such study plots will allow for an assessment in changes in forest health over time. The data collected in 2007 are considered as baseline, against which future changes can be assessed. 20 x 20 m plots were established and data collected according to standardized protocols developed by the Ecological Monitoring and Assessment Network (EMAN). Plots were established in Oak-dominated forest stands and Aspen-dominated forest stands in the Assiniboine Forest, one of the largest urban forests in North America. In addition, and as part of a project to examine the ecological implications of the use of forested riparian buffer strips as a forest management practice on long-term riparian forest health, additional EMAN-type plots were established in riparian buffers on Garner and Beresford lakes, in eastern Manitoba. Riparian areas surrounding these lakes consist of black spruce, jack pine, white spruce and balsam fir. Upland forest harvesting occurred at these lakes in the 1990s, with a 100 m buffer being left. Data for all EMAN plots are presented in this report. As part of the project, high schools students were involved in the establishment of plots and in data collection. Data from these plots have been uploaded onto the EMAN national database via the internet.

In addition to the EMAN plots, line transects were established parallel to the lakeshore, at the lakeshore, 50 m from lakeshore and 100 m from lakeshore on lakes in which upland forest harvesting had previously occurred (leaving a 100 m riparian buffer). Line transects were also established around lakes where no forest harvesting had occurred. While the proportion of trees that were either leaning or fallen in the riparian areas, and the direction

of fall were not different between riparian areas around lakes with and without forest harvesting, the width of blow down areas was significantly higher in riparian areas surrounding lakes with historic forest harvesting. It would appear that blow down occurs in riparian areas without any forest harvesting, but harvesting of adjacent upland forest may increase the likelihood of a greater width of a riparian area blowing down. The long-term fate of trees in riparian areas adjacent to areas of upland forest harvesting, and the regeneration of the forest as such sites will be studied in future years by the Manitoba Model Forest.

INTRODUCTION

Forest environments undergo continual change over time in terms of their biological communities (e.g., the occurrence and abundance of tree, shrub and herb species) and their abiotic attributes (light environment-shading, temperature environment, etc.). This change is known as forest succession. Because of the change in forest species composition through time, forest succession also plays a key role in changing habitat availability for various forest-dependent wildlife species through time.

Humans can have an influence on forests and forest succession (sometimes significantly) through direct and indirect forest management activities. Activities such as forest harvesting not only removes trees from an area, but can alter successional trajectories of the regenerating forest in ways that are different from that of a naturally regenerating forest following natural disturbances such as fire (Ehnes, 2000, 2003). However, other forest management decisions can also affect forest succession. For example, the setting aside of parts of the forest in protected areas or zones (such as forested riparian buffers) may also alter natural successional pathways in riparian forests, particularly if fire suppression activities are undertaken. Forest harvesting of upland forests will likely reduce the risk of forest fires in an area for a period of time (due to removal of older forest biomass and fuel, and due to the lower flammability of young regenerating forest), and may thus result in the isolation of riparian areas from natural disturbance processes (such as fire). The continued aging of these isolated riparian forests in a matrix of younger upland forest, and the absence of fire, is likely to have significant consequences for long-term forest health in riparian areas. However, the ecological implications of leaving these ribbons of mature forests (buffer strips) along water bodies has not received much attention.

Forested buffer strips are left along water bodies for a variety of reasons, including to provide habitat for unique riparian vegetation and wildlife, to protect water quality of adjacent water bodies (rivers, lakes, etc) and to account for other human uses (e.g., trapping, cottage areas, viewscapes). Typically in Manitoba, a 100m buffer strip is left along water bodies during logging activities. The ability of forested buffer strips to meet any or all of these objectives (e.g., protection of water quality, protection of habitat) will greatly depend on whether the trees can remain standing following harvesting of the adjacent upland forest. By removing the surrounding forest in large areas, trees in riparian areas may be subjected to increased exposure to wind and be blown over. What are the fate of trees and the rest of the forest environment in riparian areas following timber harvesting? How will the forest be renewed in riparian boreal forest environments in the potential absence of fire, or after wind blow-down events? What will forest succession look like, and how will vegetation species composition change in comparison to what would occur naturally under a wildfire regime? These questions have received little attention in a riparian forest context. Much research to date has focused on how forested buffer strips can be used to mitigate the potential effects of upland forest harvest rather than on what the long-term ecological consequences are to the riparian forests themselves.

The apparent need to balance the protection of human, riparian and aquatic values through the use of forested buffer strips, with that of allowing riparian forests to experience natural disturbances, and thus maintain natural ecological processes, has led to questioning the rationale for using buffer strips in all instances where timber harvest occurs adjacent to water bodies (MacDonald et al., 2004). As mentioned above, not only do we lack information on the long-term fate of riparian forests as a result of isolation from natural disturbances (fire) and progressive aging, we also do not know how well riparian management forestry prescriptions actually protect the values they are intended to protect (particularly if the trees blow down in the riparian forest following harvest). The latter question is a very complex one to answer.

We chose to examine the effects of harvesting of upland forests on the health and fate of forested riparian areas by two approaches. Firstly, we established line transects in riparian areas along shorelines of lakes in eastern Manitoba and assessed the proportion of trees in a standing, leaning and in a downed condition at various distances from the shoreline. This was done for different shoreline locations (east, west, north and south shorelines) and around lakes with and without adjacent upland harvesting. Secondly, we established a series of five 20x20 m long-term monitoring plots in forested riparian buffer strips in each of two lakes (Garner and Beresford lakes) in eastern Manitoba in order to collect baseline information of the vegetation community composition and forest health. Forest harvesting occurred in the upland areas surrounding these lakes in 1989-1996 (Beresford Lake) and 1999-2000 (Garner Lake). A minimum of 100m forested buffers were left around each lake during forest harvesting. The use of long-term monitoring plots in these areas will allow us to track changes in the vegetation species composition over time. Establishment of the long-term monitoring plots followed protocols developed by the Ecological Monitoring and Assessment Network (EMAN). The EMAN provides a common set of protocols for monitoring various aspects of the environment nation-wide and so allows for effective comparisons to be made across large geographic regions of various forest types. Long-term monitoring allows for the changes in the environment to be identified and quantified and will ideally allow for better environmental decisions to be made in the future.

In addition to the project objective focused on riparian forest health and forest management in eastern Manitoba, a second project objective included the establishment of long-term monitoring plots in urban forests located in the City of Winnipeg. The Manitoba Model Forest, in partnership with the City of Winnipeg Naturalist Services Branch to established monitoring plots in the Assiniboine Forest. This forest is among the largest urban forests in North America and is very different from the boreal forest. The dominant trees in the boreal forest are mostly conifers (e.g., jack pine, white spruce, black spruce, tamarack) while in the Assiniboine Forest, hardwoods such as bur oak and trembling aspen are the most prevalent. Plots were established in the Assiniboine Forest to provide long-term data on an urban forest. Nine EMAN monitoring plots were established in the Assiniboine Forest (5 in oak-dominated forest stands, and 4 in aspen-dominated forest stands). In addition, there was strong interest expressed by a school in Winnipeg (Centre Scolaire Leo Remillard) and by the Winnipeg-based environmental non-government organization, Save our Seine, to establish an environmental monitoring program in one of Winnipeg's newest protected areas, the Bois des Esprit (a riparian forest along the Seine River). However, due to time constraints, only a single EMAN plot was partially established in the Bois des Esprit (with the help of Centre Scolaire Leo Remillard). Because of this, the data from the Bois des Esprit are not presented in this report. A full suite of 5 EMAN plots will be established in 2008.

METHODS

EMAN Plots

EMAN plots were established from June to September, 2007 and the vegetation measured following the protocol of Roberts-Pichette and Gillespie (1999). A total of five 20 x 20 m plots were established in the riparian buffer strips (riparian forests) surrounding each of Garner and Beresford lakes in eastern Manitoba. Five 20 x 20 m plots were established in Open Oak stands in the Assiniboine Forest. However, only four 20 x 20 m plots were established in Open Aspen stands of the Assiniboine Forest. A general description of each site is presented in the Results and Discussion section. All trees with a diameter at breast height (dbh) of greater than 10 cm (except in the Open Oak stands in the Assiniboine Forest where, because of their small size, trees with a dbh of greater than 5 cm), were tagged with an aluminum tag labeled with the forest type/location, plot number, and tree number. Dbh was measured with a dbh tape to the nearest 0.1 cm. The location of each tree in the 20 x 20 m plots was recorded by measuring the distance of each tree from two sides of the plot. This information was then entered into the EMAN national database via the internet.

For each tree, a number of basic health assessments were conducted. These included tree condition, crown class, crown rating and stem defects. Tree condition was recorded which included categories of Alive Standing, Alive with a Broken top, Alive Leaning, Alive Fallen, Alive standing with a Dead top, Dead Standing, Dead Broken, Dead Leaning, and Dead Fallen. Crown class was assessed according to the following categories: dominant, co-dominant, intermediate and suppressed. Dominant trees are those whose crowns are above the general layer of the canopy and the crown receives full sunlight. Co-dominant trees are at the average height of the canopy and receive light on the top of the crown but little from the sides. Intermediate trees are shorter than the canopy and receive little light. Suppressed trees are much shorter than the canopy and receive no direct light. The crown rating of each tree was evaluated using a five point scale based on the proportion of fine dead fine branches in the canopy. Category 1, for crown rating, had less than 10% fine branch mortality, category 2 had 10-50% mortality, category 3 was more than 50% mortality, category 4 was dead of natural causes, and category 5 was dead of human causes. The stem defects that were recorded were the presence of a decay fungus (1), a dry seam or frost crack (2), a wet or bleeding seam or frost crack (3), an open wound (4), a closed wound (5), a canker (6), insect damage (7), pruned (8), and animal damage (9).

Regeneration (shrub and sapling) plots were established in each corner of the large 20 x 20 m plot. Each regeneration plot was 5 x 5 m. Therefore there were 4 regeneration plots per 20 x 20 m plot. Saplings greater of greater than four centimetres dbh were tagged like the trees were. A note was made whether the saplings were alive or dead. The species of all saplings was recorded.

Herb plots (1 x 1 m) were set up 1 m outside the large plot and halfway along each side. Therefore, there were 4-1 x 1 m herb plots for each 20 x 20 m plot. All species that were present in the plot were recorded and their percent cover was estimated visually. Any additional species that were present in the larger 20 x 20 m plot that were not observed in the smaller herb plots were also recorded to provide a complete inventory of herbs.

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Three woody debris transects, of 45.15 m in length, were established at each plot. The transects originated at 3 of the corners of the 20 x 20 m plot and followed a path of 45.15 m outward from the plot corner. All trees that crossed the transect, with a diameter of greater than 10 cm (or 5 cm in the open oak plots in the Assiniboine Forest), were identified to species if possible and the stage of decomposition rated according to a five point scale. Diameter was measured at the point at which the log crossed the line transect. For decomposition classes, Category 1 was the least decomposed with the bark intact, twigs present, a round shape, and the log elevated. Category 2 had the bark intact, twigs absent, a round shape, and the log elevated but starting to sag. Category 3 had a trace of bark, twigs absent, and the log sagging near the ground. Category 4 had bark absent, a soft texture, round to oval shape, and the entire log resting on the ground. Category 5 had bark absent, twigs absent, soft texture, oval shape, and was lying on the ground being difficult to pick off the ground without breaking it.

The amount of light reaching the forest floor was measured in five random locations within each 20 x 20 m plot through recording light intensities at the forest floor and simultaneously in an open area that was not shaded. These measurements were made with a GE Light Meter Model 217. The percent transmission was calculated by dividing the light reading inside the plot by the light reading outside the plot.

The height of five dominant trees, adjacent to and representative to the dominant trees in the plot, was measured using a Suunto Clinometer Model PM-5/360PC. The age of these same trees was determined through using an increment borer with the core taken at 1.3 metres above ground level. No trees were cored in the Assiniboine Forest oak plots.

Riparian Transects

Riparian forest transects were established from June to August, 2007 around 6 lakes in eastern Manitoba. A map showing the location of each lake is found in the Results and Discussion section. Transects were located in riparian areas of lakes which had historical timber harvesting in adjacent upland areas, and also in riparian areas of lakes which have never experienced adjacent upland timber harvesting (reference lakes). Line transects were established on different sides of each lake (e.g., along south shorelines, east, north and west shorelines). On each shoreline, at least 3 – 100m long transects running parallel to the shore were established: 1 transect along the lakeshore edge, 1 transect approximately 50m from the lakeshore, and 1 transect either close to the timber harvest/cutblock edge (for lakes with harvesting) or adjacent to a natural forest edge such as a peatland (for lakes without harvesting). Each line transect was 2 m wide. Along the length of each transect, standing, leaning and downed trees were recorded. For each tree, the following parameters were assessed: species, diameter at breast height, tree condition, bearing (direction) of fall or lean, decomposition class, crown rating, crown class and defects. In addition, for areas of blow-down, the maximum width of the blow down either at the lake shore and at the cut block edge or natural forest edge (for reference lakes) was estimated. A total of 93 line transects were established and evaluated.

In order to ensure that the riparian forest stands around all 6 lakes were as similar as possible, the 1997 Tembec digital Forest Resource Inventory (FRI) was utilized. Using the FRI, and as much as possible, the riparian forests selected represented older (stand origin of 1912-17) jack pine-dominated stands, with a crown class of 3 or 4 and a moisture class of 1 or 2. Prior to establishing transects in the field, the location of each 100 m transect was determined in the office, without prior knowledge of where areas of blow-down may be found around each lake. This was done to avoid introducing sampling bias into the experimental design such as deliberately selecting areas of blow down or deliberately avoiding them.

Data Analyses

EMAN Plots

All calculations for the EMAN plots are reported on a per hectare basis, unless otherwise noted. Abundance is the number of trees in a given area. Basal area is the cross-sectional area of all trees in a given area, and is based on dbh. The importance value is composed of the sum of relative density, relative dominance, and relative frequency. Importance Value gives an indication of the structural role of a species in a stand. It is useful for making comparisons among stands in reference to the species composition and stand structure (Roberts-Pichette and Gillespie, 1999). The relative values are determined by dividing the value for a particular tree species by the sum of the values for all tree species. The density is the number of individuals per unit area. The dominance is the area a species occupies per unit area, based on dbh. The frequency is the proportion of plots in a stand in which a species occurs.

Averages and standard deviations were calculated for all the tree parameters. The average and standard deviation of each seedling and shrub, and herb species were calculated for each stand type. For woody debris, the average volume and average number of pieces in each transect were calculated, along with the standard deviation for each. The volume of wood debris was determined by Volume (m^3/hectare) = $10\ 000 * \pi^2 * \Sigma d^2 / 8L$ where d is the diameter (metres) of each piece and L is the length of the woody debris transect (Ehnes, 2000).

Riparian Transects

For the Riparian Transects, averages were computed for the transects on each side of the lakes (north, south, east, west) and for each location (shoreline, 50m from shoreline, cutblock boundary/natural stand boundary) with respect to the maximum width of blow-down, the proportion of trees in a leaning or fallen condition, the direction of tree lean or fall and defects (in alive standing trees). Standard deviations were not calculated for all parameters as some of the categories contained only one or two transects. To determine the proportion of trees fallen in each cardinal direction, north was defined as being between 315 and 45 degrees, east between 45 and 135 degrees, south between 135 and 225 degrees, and west between 225 and 315 degrees.

RESULTS and DISCUSSION

General Description of Study Sites

EMAN Study Plots

EMAN study plots were established in riparian forest areas around 2 lakes (Garner and Beresford lakes) in the boreal forest of the Manitoba Model Forest, and in the Assiniboine Forest and the Bois des Esprit within the City of Winnipeg. Since this was the first time that monitoring was conducted in these plots, we can only document the current condition of each stand. In essence, the data collected in the plots in 2007 is considered as baseline information. It is not possible to determine, for example, how adjacent upland forest harvesting around Garner or Beresford lakes have influence the riparian forests surrounding those lakes. Future monitoring will allow for the determination of how the stands have changed through time.

Garner and Beresford lakes are located in the northeast corner of the Manitoba Model Forest area (Figs. 1 & 2). The Manitoba Model Forest area is located in the boreal forest and is typified by Precambrian shield granite rock outcrops and low-lying peatlands. Main tree species on upland sites include jack pine, black and white spruce and trembling aspen. Main tree species in poorly drained and saturated peatlands include black spruce and tamarack. A more detailed description of the Manitoba Model Forest area is found in Dupont et al. (2006) and Kotak and Lidgett (2004).

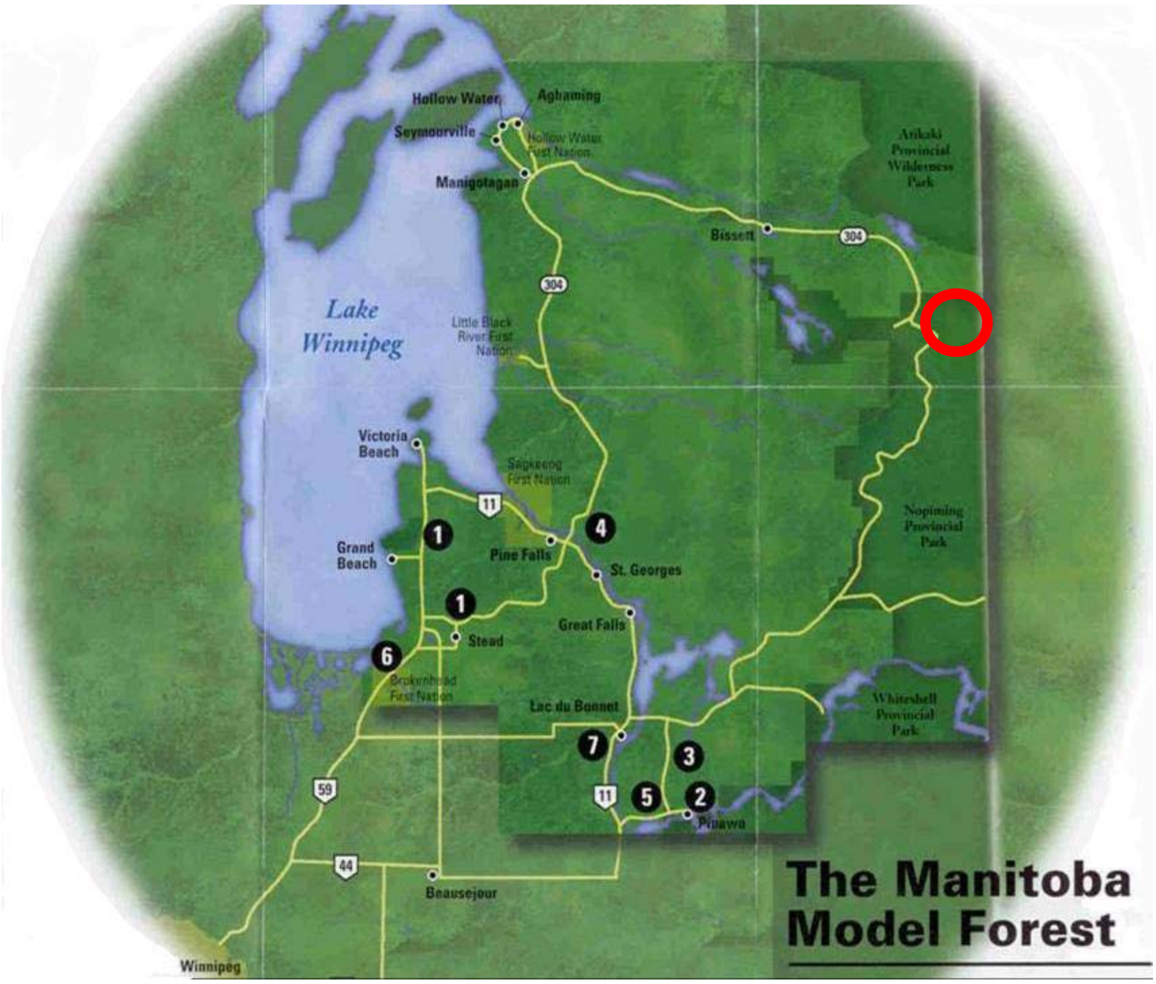


Figure 1. Map of eastern Manitoba showing the location of the Manitoba Model Forest and the general location of Garner and Beresford lakes (red circle).

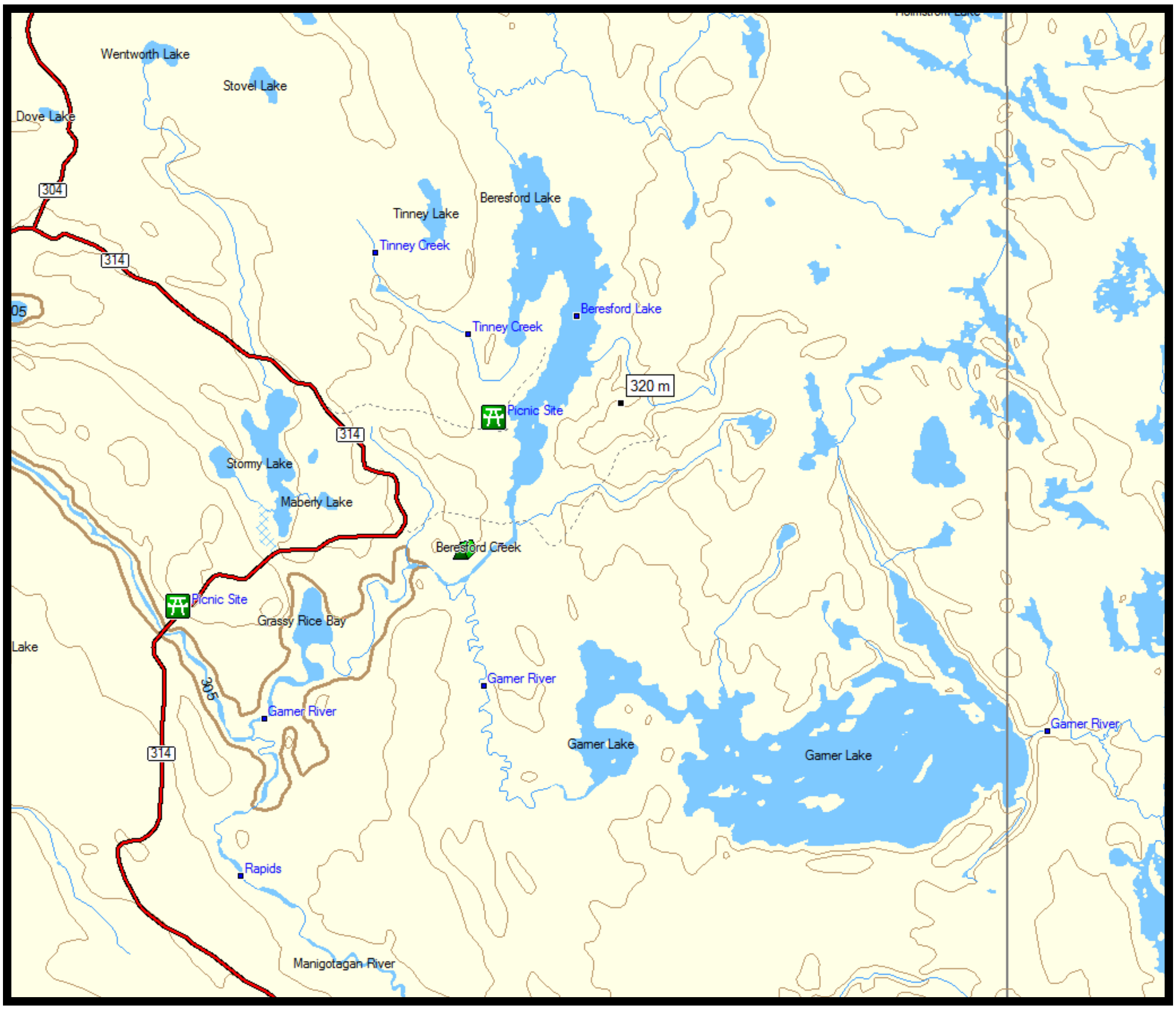


Figure 2. Map showing location of Garner and Beresford lakes.

EMAN monitoring plots were established along the south shore of Garner Lake (Fig. 3). According to the 1997 Tembec FRI, the riparian forest stand in which the plots are located was a mixed-wood forest consisting of black spruce (40%), white spruce (30%) and balsam fir (30%). The V-type was 27 and the Subtype was 15. The year of origin was 1918 and the stand was 18.7 ha in area.

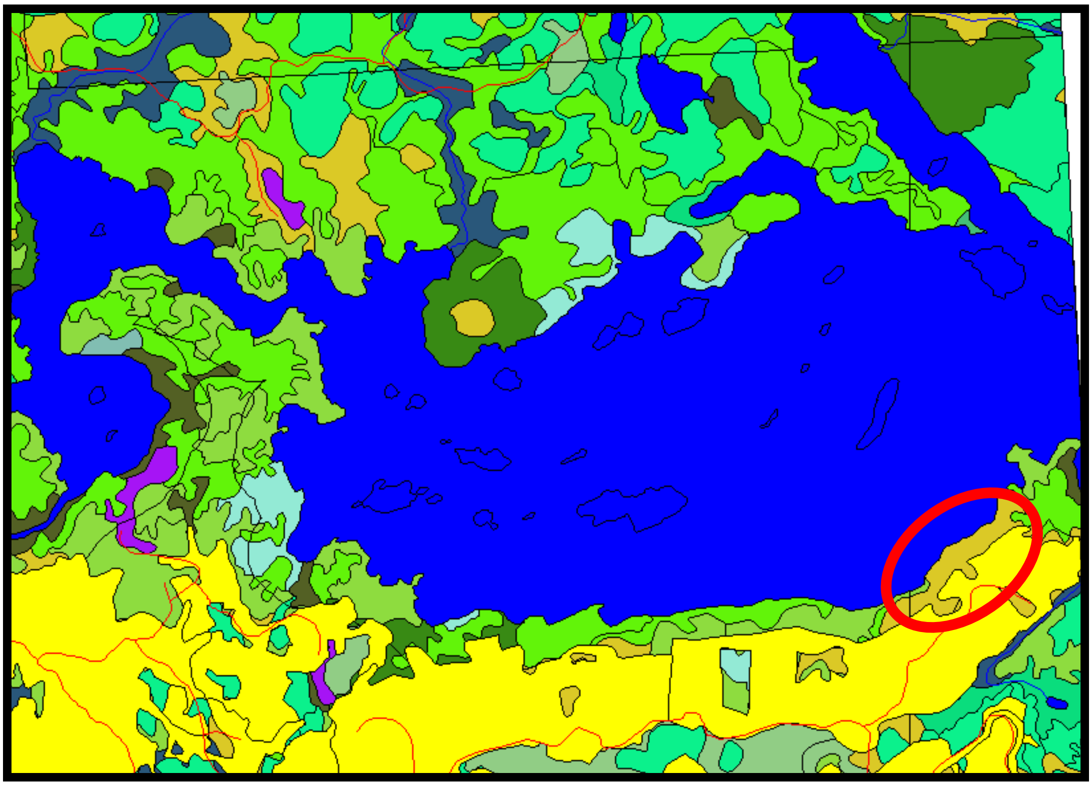


Figure 3. Location of riparian forest stand and EMAN study plots (red ellipse) along south shore of Garner Lake. Note: yellow areas on south shore on map indicate areas of forest harvest.

EMAN study plots were also established along the eastern shore of Beresford Lake (Fig. 4). According to the 1997 Tembec FRI, the riparian forest stand in which the EMAN plots were located was a mixed-wood forest containing black spruce (30%), jack pine (30%), balsam fir (20%), white spruce (10%) and trembling aspen (10%). The V-type was 28 and the Subtype was 14. The year of origin was 1895 and the area was 24.2 hectares.

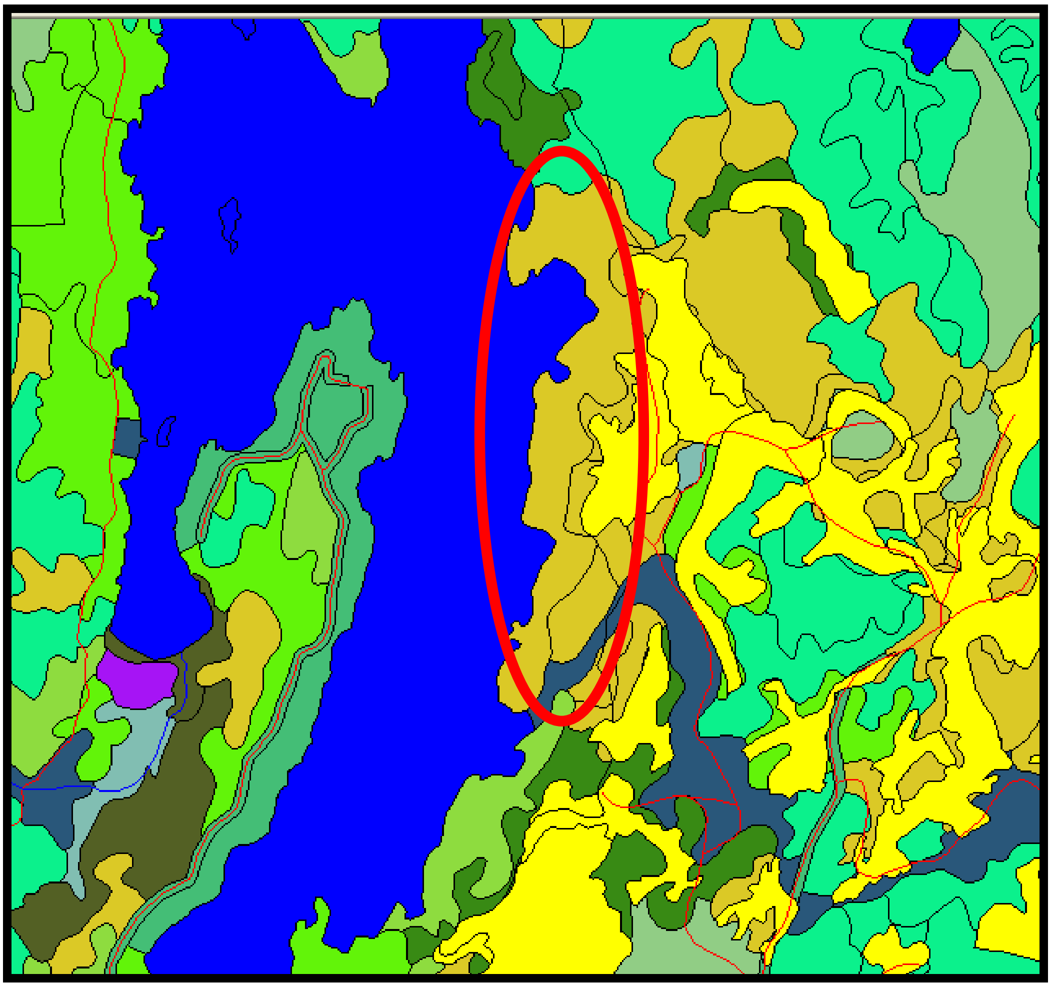


Figure 4. Location of riparian forest stand and EMAN study plots (red ellipse) along the eastern shore of Beresford Lake. Note: yellow areas on map indicate areas of forest harvest.

Both the Garner Lake and Beresford Lake riparian EMAN plots were located in over-mature forests. In addition, both areas were defoliated by forest tent caterpillar (severity class 2) in 2001, and the riparian forest stand along the east shore of Beresford Lake also experienced a spruce budworm outbreak (severity class 2) in 1995.

The EMAN study plots in the Assiniboine Forest were located within the City of Winnipeg (Fig. 5). The Assiniboine Forest is the largest urban forest in Canada, with an area of 700 acres. The forest is comprised of a mixture of upland aspen and oak forest and marsh. There forest has been characterized in detail by Ruta (1981) but has not been studied since.

The study plots were all located in the part of the Assiniboine Forest located south of Grant Avenue (Fig. 6).

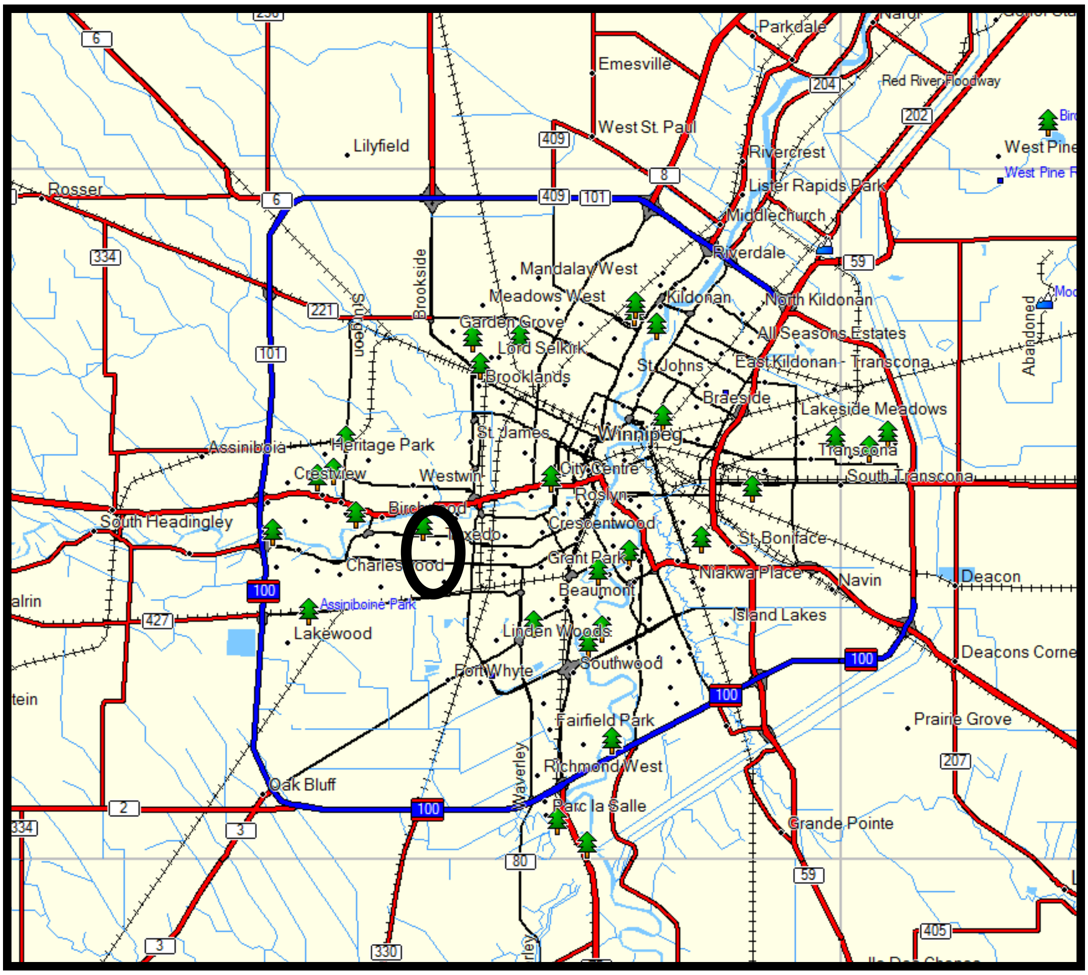


Figure 5. Map of the City of Winnipeg showing approximate location of the Assiniboine Forest (black ellipse).

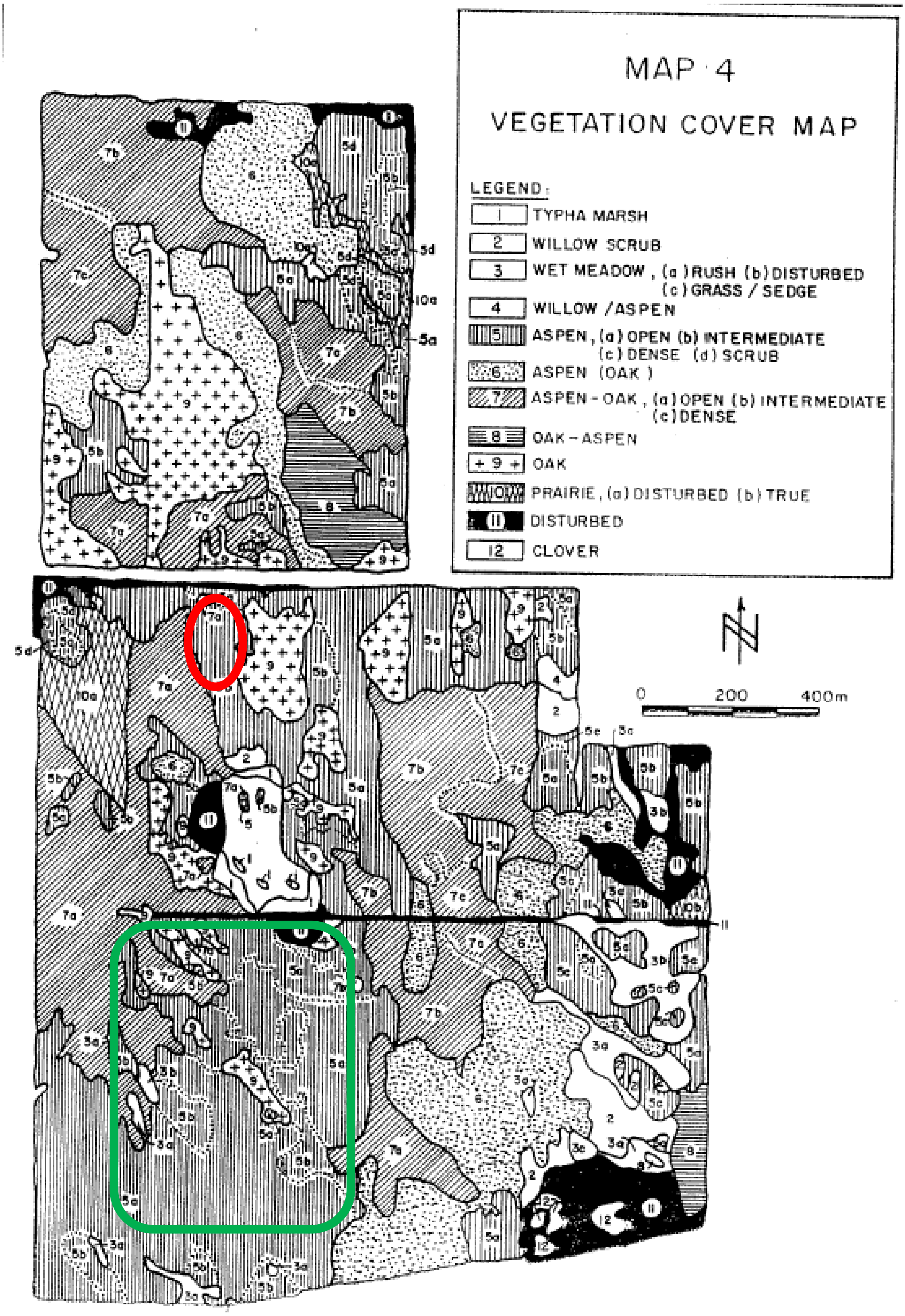


Figure 6. Vegetation map of Assiniboine Forest showing general location of EMAN study plots in Open Oak forest stands (upper red circle) and Open Aspen forest stands (lower green box). Original vegetation map from Ruta (1981).

Since the establishment of EMAN study plots in the Bois des Esprit did not progress very far in 2007, a description of this study area is not presented in this report, but will be described in a future report.

Riparian Transect Study Sites

The riparian forest transect sites were all located around lakes within a 10 km distance of each other in the Manitoba Model Forest area, close to Springer Lake in Nopiming Provincial Park (Fig. 7). The shorelines around each lake are characterized by granite ridges, containing mature to over-mature jack pine forests. Soils were generally very shallow, with trees going directly on the rock ridges in many cases.

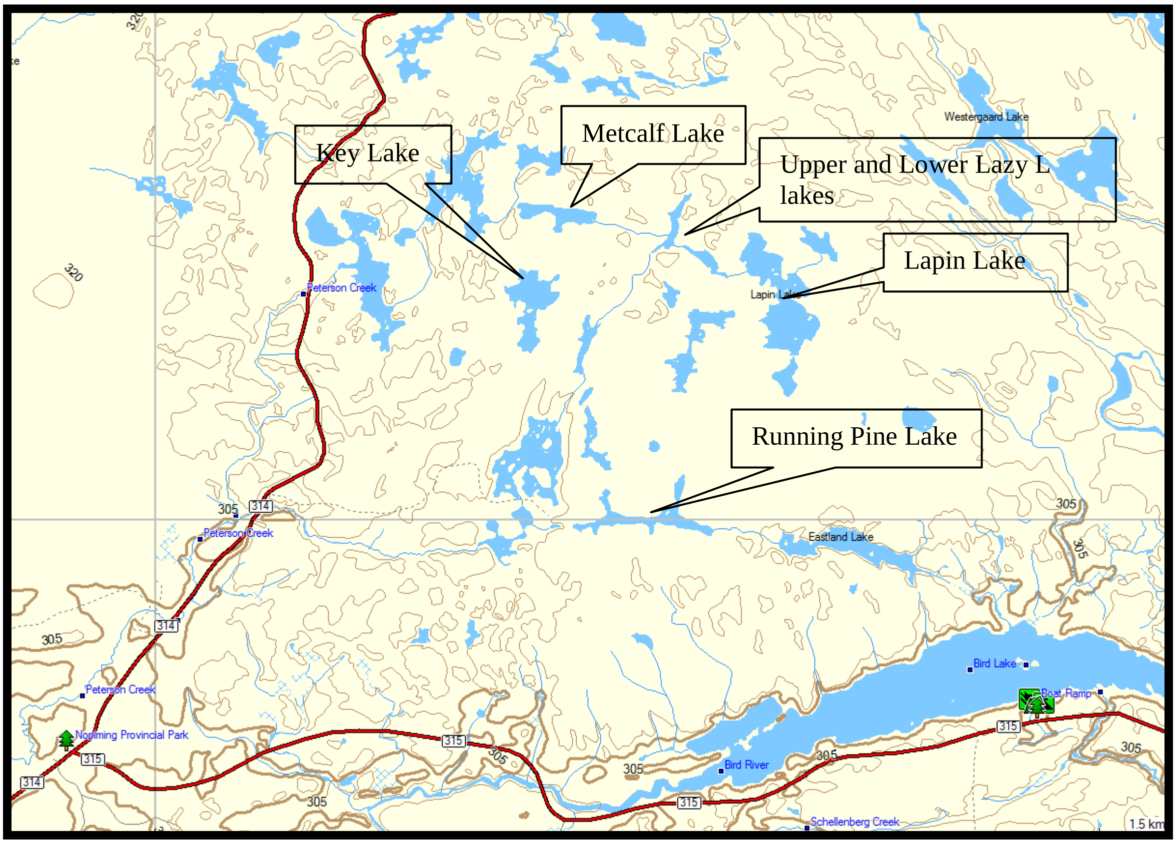


Figure 7. Location of study lakes containing riparian forest transects.

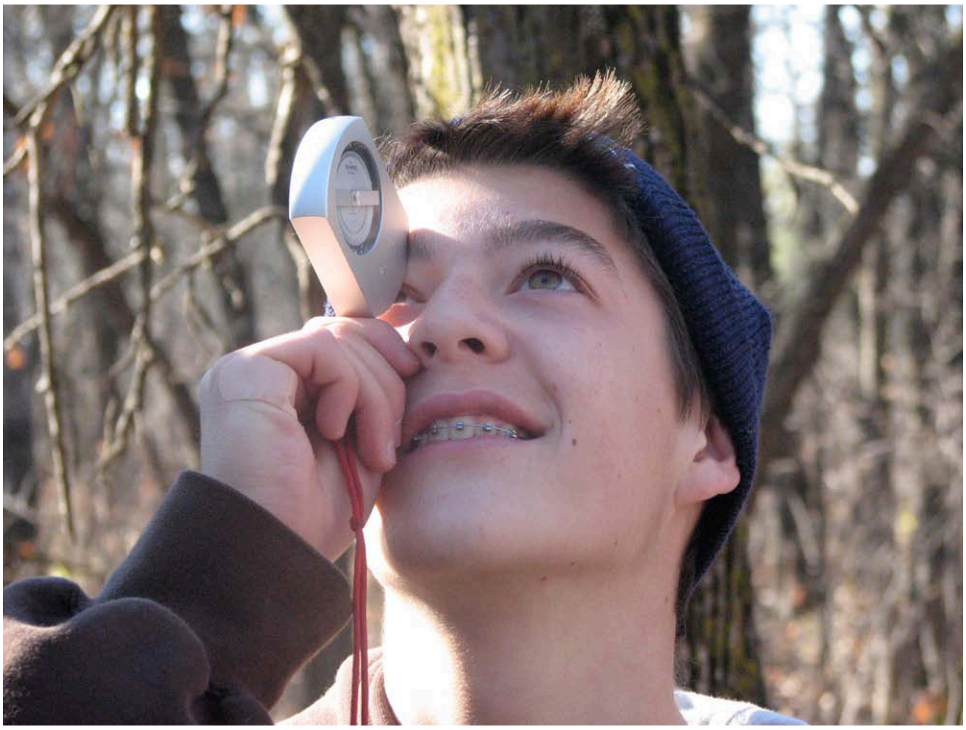
Forest harvesting occurred in the upland forest adjacent to Metcalf Lake, Lower Lazy Lake, Lapin Lake, Key Lake, and Running Pine Lake during the period of 1999 to 2003.

High School Participation in Monitoring

The establishment of forest monitoring sites by the Manitoba Model Forest, as part of their Terrestrial Bio-monitoring project, began in 2005. A key component of the project is the involvement of high school students from the Manitoba Model Forest area. Over the years, the Manitoba Model Forest has taken grades 10-12 students out to the study plots, discussed issues relating to forest sustainability and provided training to the students on how to collect monitoring data. The students then assisted in the collection of data. Not only do the students learn important skills, but gain a greater appreciation of our forests, as well as contribute directly to the database of monitoring information in the study plots. Typically, the classes assist in data collection during a 1 day field trip in the spring and another field trip in the fall. Some of the students have participated multiple years, becoming mentors to some of their fellow students.

In the fall of 2007, the science classes from 4 high schools (Leo Remillard School in Winnipeg, and Lac du Bonnet, Powerview and Wanipigow schools in the MBMF area of eastern Manitoba) participated in establishing and monitoring forest plots. In total, over 100 students participated. For each class, the students attended a 1-day field trip to our study plots, were instructed how to establish study plots and how to measure the various forest attributes. This included identifying tree species, measuring dbh of trees and tagging trees, conducting tree health assessments, measuring light intensity in the study plots, as well as soil and air temperature and relative humidity. The students also learned how to estimate the height of trees using a clinometer and how to age a tree using an increment borer. With this information, the students then helped to establish a plot and collected their own data using our scientific equipment. Prior to the field trip, a presentation was made to each class on the project and their involvement. The field trips occurred in September and October, 2007. Figures 8 a-f provide some photographs of students participating in the field trips.

Figure 8 a. Students from Centre Scolaire Leo Remillard gathered around "Woody the Spirit Tree" in the Bois des Esprit.



Figures 8 b&c. Students from Centre Scolaire Leo Remillard measure tree height using a clinometer (top photo) and measure the diameter of an oak tree (lower photo) in the Bois des Esprit.

Figures 8 d&e. Students from Powerview School (upper photo) and Wanipigow School (lower photo) at the Pine Creek Trail near Pine Falls.

Figure 8f. Students from Lac du Bonnet Senior School visiting a monitoring site in an area which experienced a recent forest fire.

Trees in EMAN Plots

As expected, there was a difference in canopy tree species composition and in the number of trees of each species in each forest type (Fig. 9). The Garner Lake plots had the greatest diversity of trees with six species present. In contrast, the aspen plots in the Assiniboine Forest had the lowest diversity with only two species present and trembling aspen being the most abundant (Fig. 9). As indicated by the stand name, the oak stand in the Assiniboine Forest was dominated by bur oak. Generally, basal area was proportional to abundance (Fig. 10).

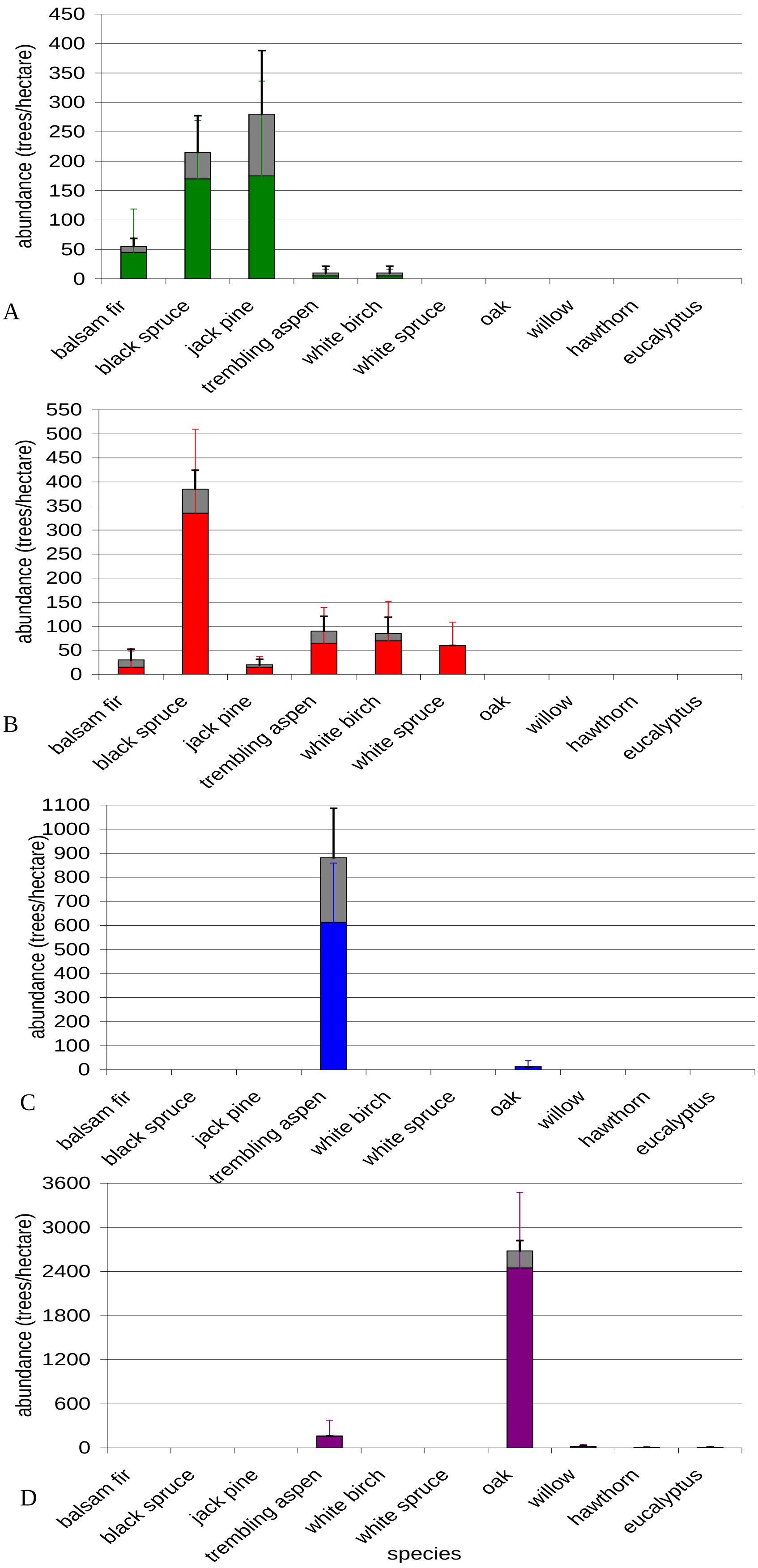


Figure 9. Abundance and standard deviations for each tree species present in the different forest types. Coloured bars: live trees; grey bars: dead trees. A: Beresford Lake, B: Garner Lake, C: Assiniboine Forest aspen, D, Assiniboine Forest oak.

In the Beresford Lake plots, black spruce and jack pine were the most abundant live standing trees, with jack pine having a larger basal area. The most abundant dead standing species was jack pine, though dead standing black spruce had a greater basal area.

The Garner Lake plots had black spruce as the most abundant species (Fig. 9) and this species also had the greatest basal area (Fig. 10). Some dead trees of every species were present, though they were not abundant (Fig. 9). The Assiniboine Forest plots had low diversity of trees with one species being most prevalent (Fig. 9). In the aspen plots, trembling aspen was most abundant, with very few bur oaks present. In the oak plots, the trees were the densest of any of the forest types. This was partly due to defining a tree in these plots as being greater than 4 cm dbh (compared to 10 cm dbh in the other stand types). Approximately ¼ of the aspen trees were dead in the aspen plots. A very small proportion of the oaks were dead in the oak plots.

The species with the greatest importance value in the Beresford Lake plots were black spruce and jack pine with approximately equal contributions of relative frequency, relative dominance, and relative density (Fig. 11). In the Garner Lake plots, black spruce had the largest importance value. In the aspen plots, trembling aspen had the largest importance value of nearly the maximum of 300 while in the oak plots, oak had the largest importance value, again nearly the maximum of 300 (Fig. 11).

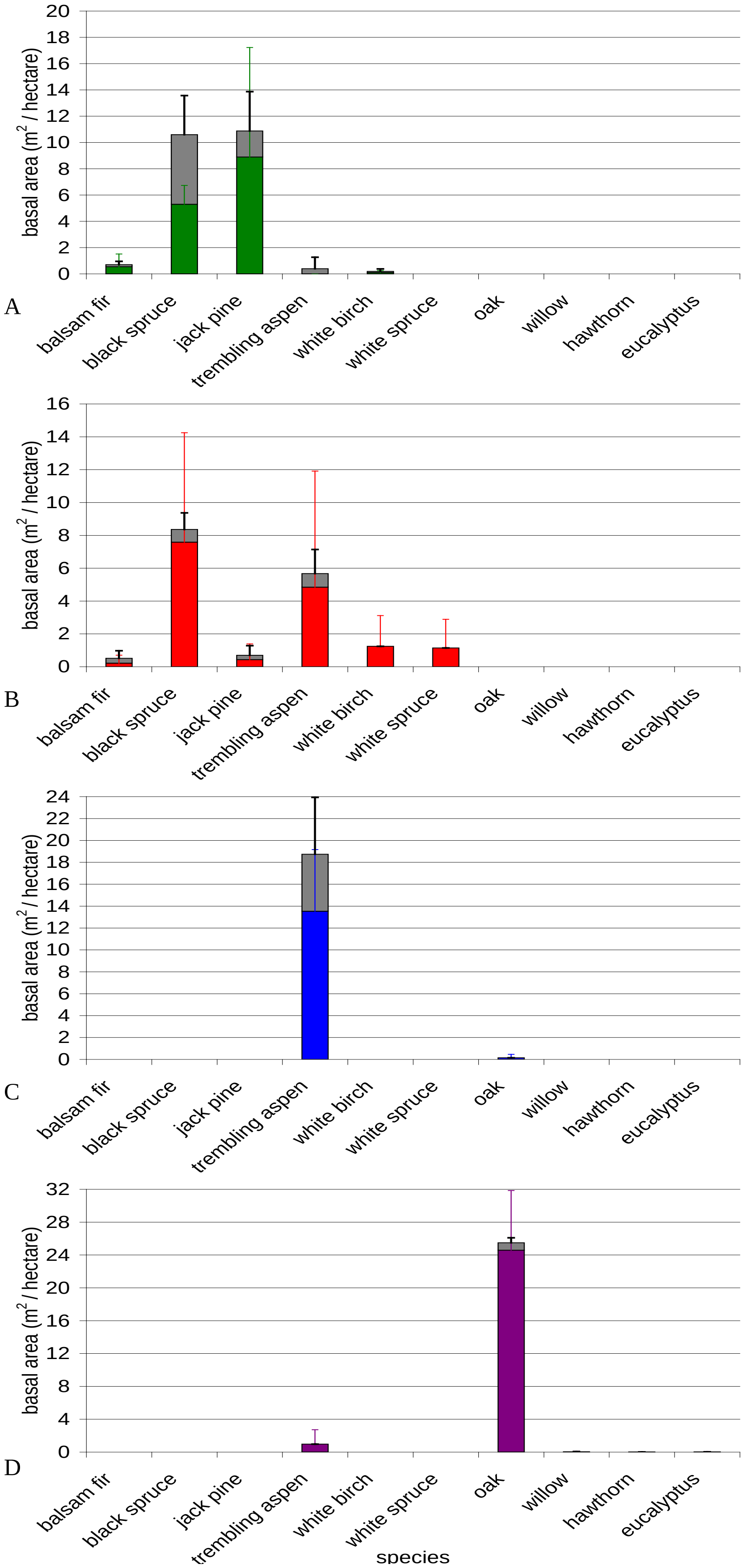


Figure 10. Basal area and standard deviations for each tree species present in the different forest types. Coloured bars: live trees; grey bars: dead trees. A: Beresford Lake, B: Garner Lake, C: Assiniboine Forest aspen, D, Assiniboine Forest oak.

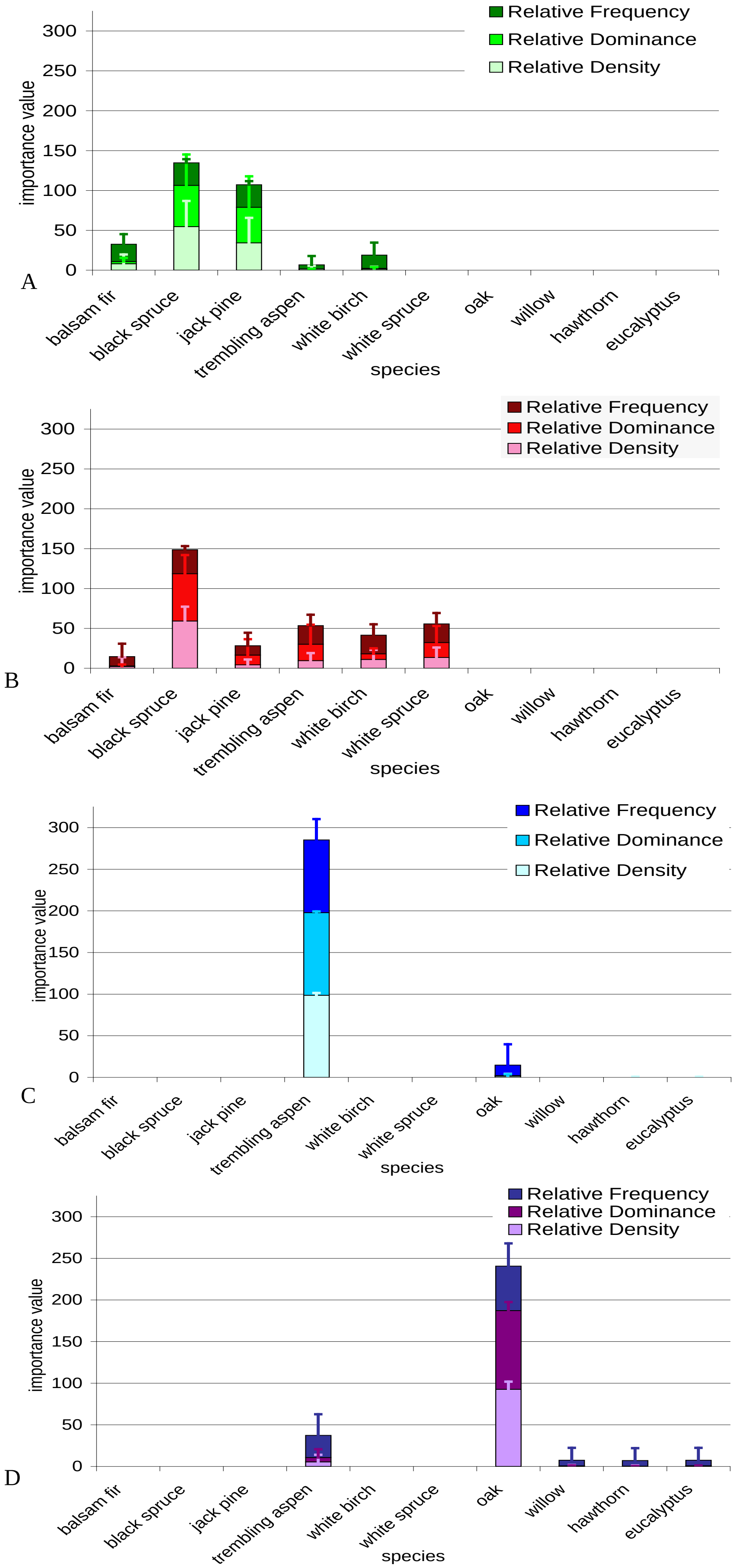


Figure 11. Importance value, composed of the averages and standard deviations of relative frequency, relative dominance, and relative density for each species in each of the forest types. A: Beresford Lake, B: Garner Lake, C: Assiniboine Forest Aspen, D: Assiniboine Forest oak.

In all forest types the tree condition of the majority of every species present was alive standing, with most of the remainder being dead standing (Fig. 12). This is probably because dead trees do not remain standing for very long and so fall relatively soon after death and so do not remain as standing trees in the plots. Dead standing trees were the next most abundant with the remaining categories of trees being rare or absent (Fig. 12).

Most trees of the boreal forest plots were very healthy, with a class 1 crown rating. In the Beresford Lake plots, the two most abundant species, jack pine and black spruce had the highest numbers of class 4 trees, dead of natural causes. This is an area that had previously experienced a spruce budworm outbreak. Very few class 2 or 3 trees were present (Fig. 13). The same was true in the Garner Lake plots. The aspen plots of the Assiniboine Forest were the only ones to have trees that were human killed (Fig. 13). Furthermore, the aspen stand was the only stand to have trees of all five crown ratings. Ratings 1, 2, and 4 were quite abundant, 275-350 trees per hectare, while the abundance of trees with ratings of 3 and 5 had abundances of approximately 50 trees per hectare (Fig. 13). The oak plots of the Assiniboine Forest did not have trees with a crown rating of 1 being the most dominant. Crown rating 2 was the most abundant with class 1 following. In particular, many of the smaller trees had dead branches. This was not the case for the larger oak trees. Crown rating 3 and 4 were also present but much rarer (Fig. 13).

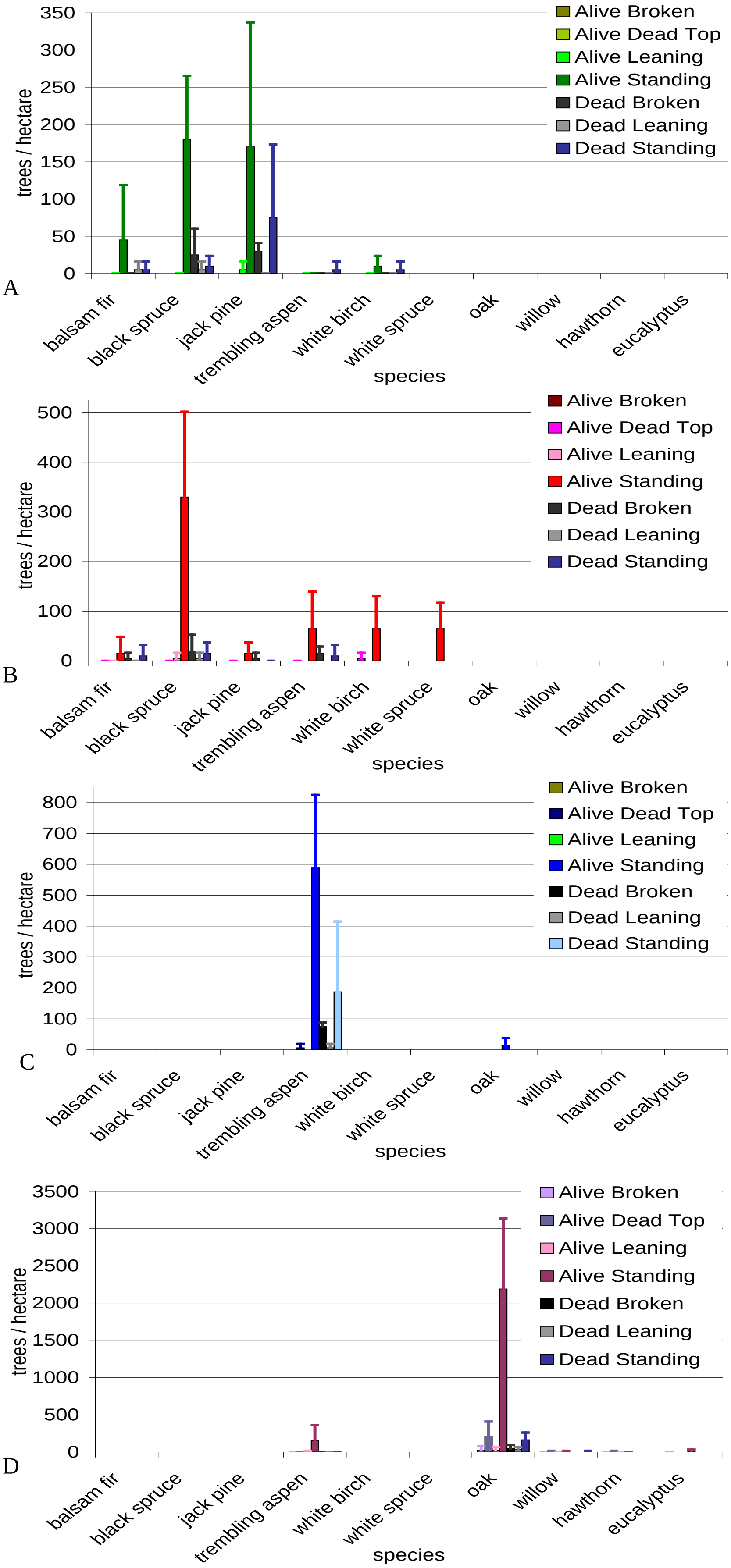


Figure 12. Average and standard deviation of the density of trees of each condition in each of the forest types. A: Beresford Lake, B: Garner Lake, C: Assiniboine Forest aspen, D: Assiniboine Forest oak.

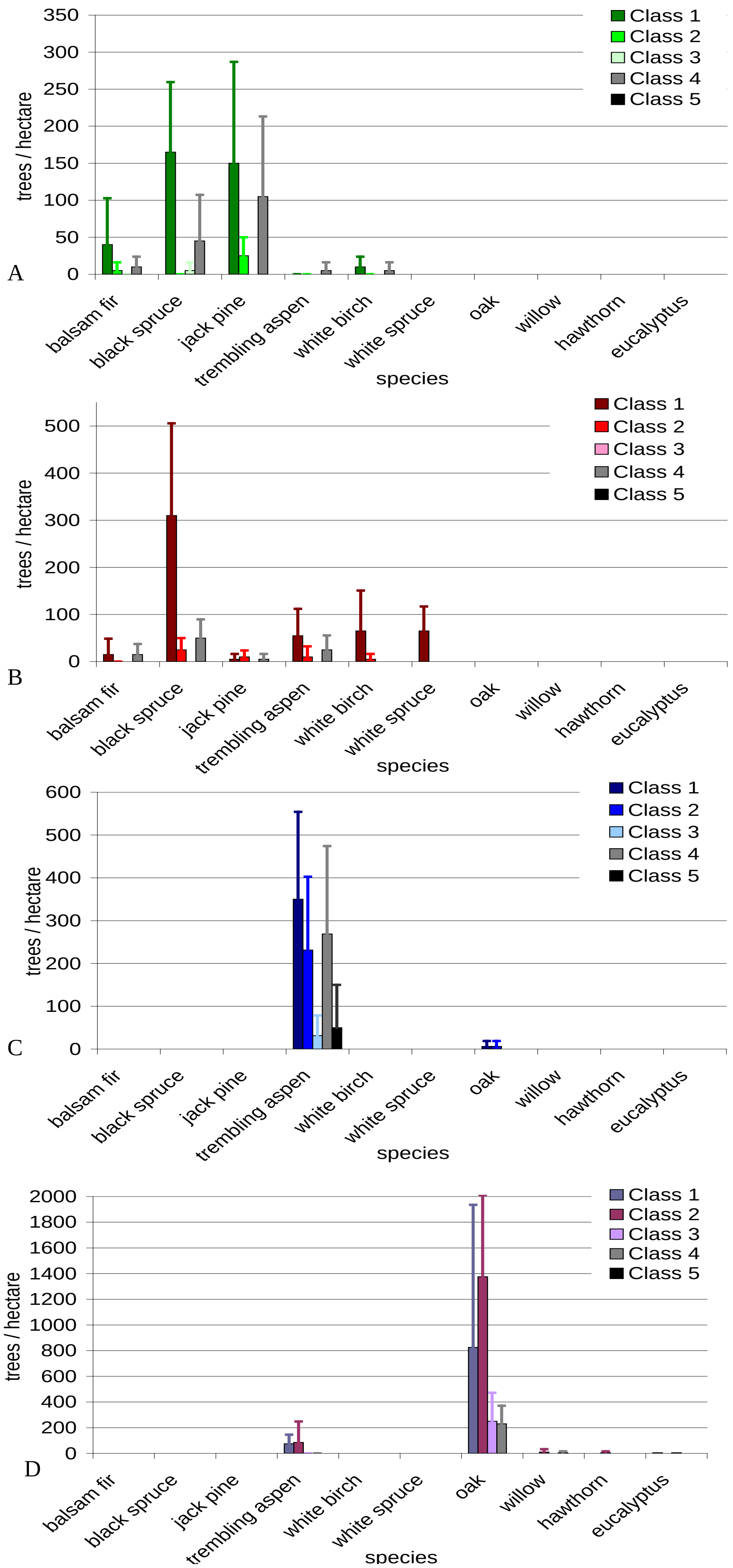


Figure 13. Average and standard deviation of the density of the trees of each species of each crown rating in each of the forest types. Class 1: <10% mortality, 2: 10-50% mortality, 3: >50% mortality, 4: dead of natural causes, 5: dead of human causes. A: Beresford Lake, B: Garner Lake, C: Assiniboine Forest aspen, D: Assiniboine Forest oak.

In the Beresford Lake plots, there were dominant black spruce and jack pine trees with these two species making up most of the canopy, being the only co-dominant species present (Fig. 14). The most abundant intermediate species were balsam fir and black spruce, with jack pine and white birch also being present. Balsam fir was the only suppressed species (Fig. 14). The Garner Lake plots were the most varied with dominant trees of black spruce, trembling aspen, and white spruce being present. All six species that were present in these plots were co-dominant (Fig. 14). Black spruce was the most abundant intermediate species though all others, with the exception of jack pine, were present as intermediates as well. No suppressed trees were present. The trembling aspen trees in the aspen plots were mainly co-dominant with a few intermediate individuals present. The oaks in the oak plots were well divided between co-dominant, intermediate and suppressed, with their abundances being ranked in that order (Fig. 14). All four classes of aspens were present in the oak plots, though in very low abundances (Fig. 14).

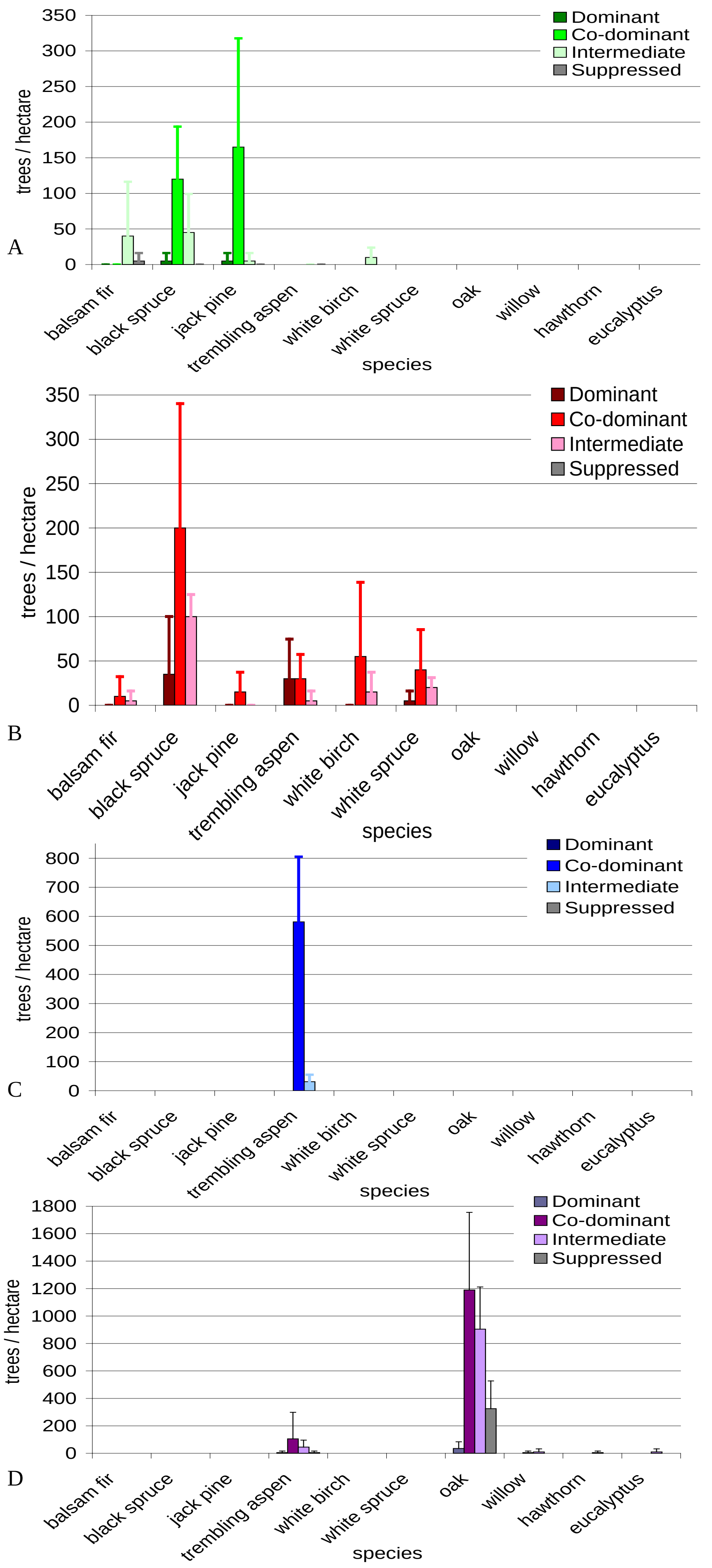


Figure 14. Average and standard deviation of the density of the trees of each crown class in each of the forest types. A: Beresford Lake, B: Garner Lake, C: Assiniboine Forest aspen, D: Assiniboine Forest oak.

In the Beresford Lake plots, open and closed wounds were the most common defects. In the Garner Lake plots the most common defects were closed wounds and insect damage (spruce budworm). In the aspen plots, closed wounds, dry frost cracks, decay fungi, and insect damage were the most common defects, in decreasing abundance. In the oak plots, closed wounds were the most common defects followed by dry frost cracks (Fig. 15).

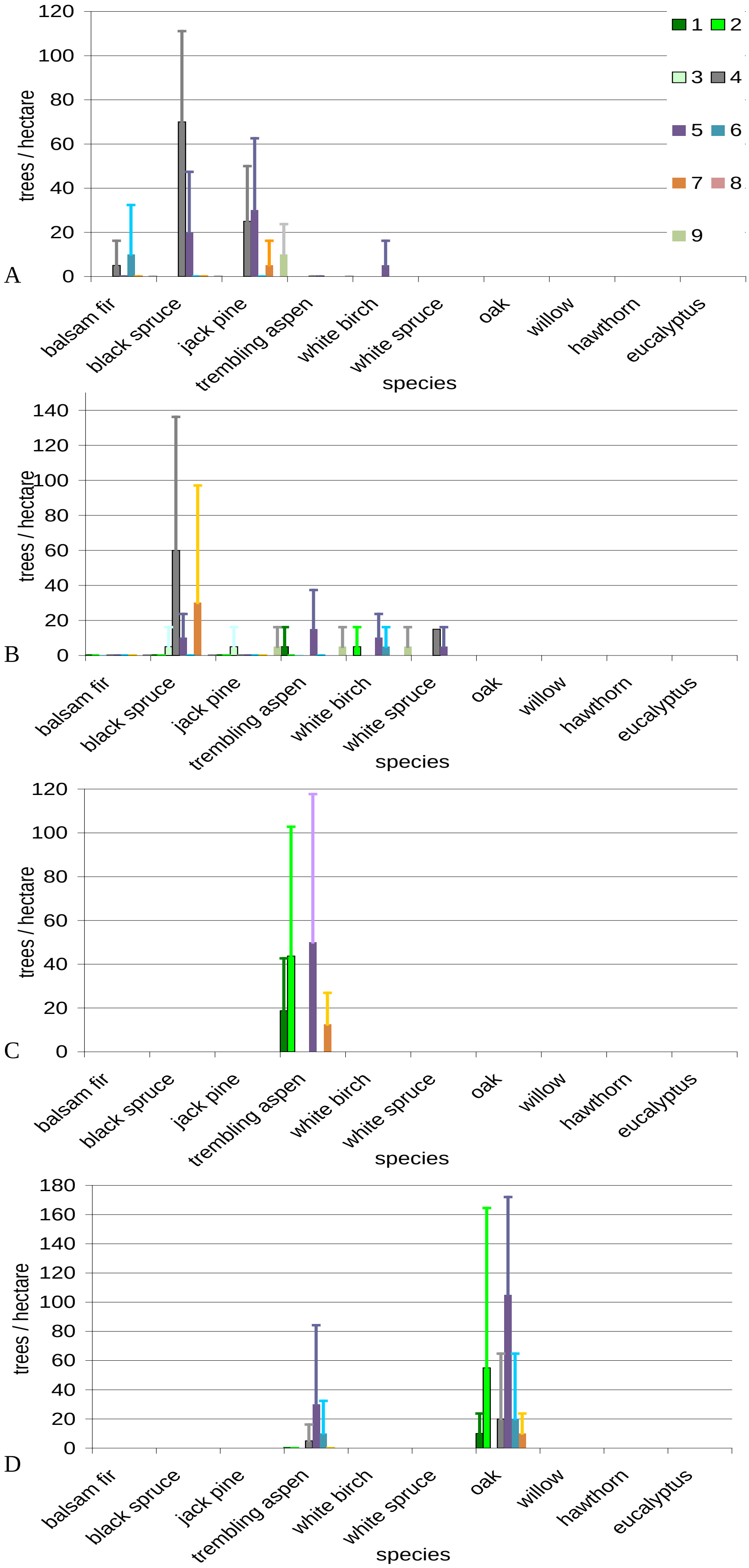


Figure 15. Average and standard deviation of the density of each defect for each of the tree species in each forest type. 1: decay fungus, 2: dry frost crack, 3: wet frost crack, 4: open wound, 5: closed wound, 6: canker, 7: insect damage, 8: pruned, 9: animal damage. A: Beresford Lake. B: Garner Lake. C: Assinboine Forest aspen. D: Assiniboine Forest oak.

Seedlings, Saplings, Shrubs, and Herbs

Depending upon the species and the forest type, the variability in the number of shrubs and small trees in each quadrat varied from highly variable to highly consistent (Fig. 16). Rose, saskatoon, trembling aspen, and currant were present in all four forest types (Fig. 16). The plots in the boreal forest, the Beresford Lake and Garner Lake plots, had the greatest diversity of shrubs and small trees, 16 and 17 species respectively. The aspen plots in the Assiniboine Forest had 10 species present while the oak plots had 11 species present (Fig. 16).

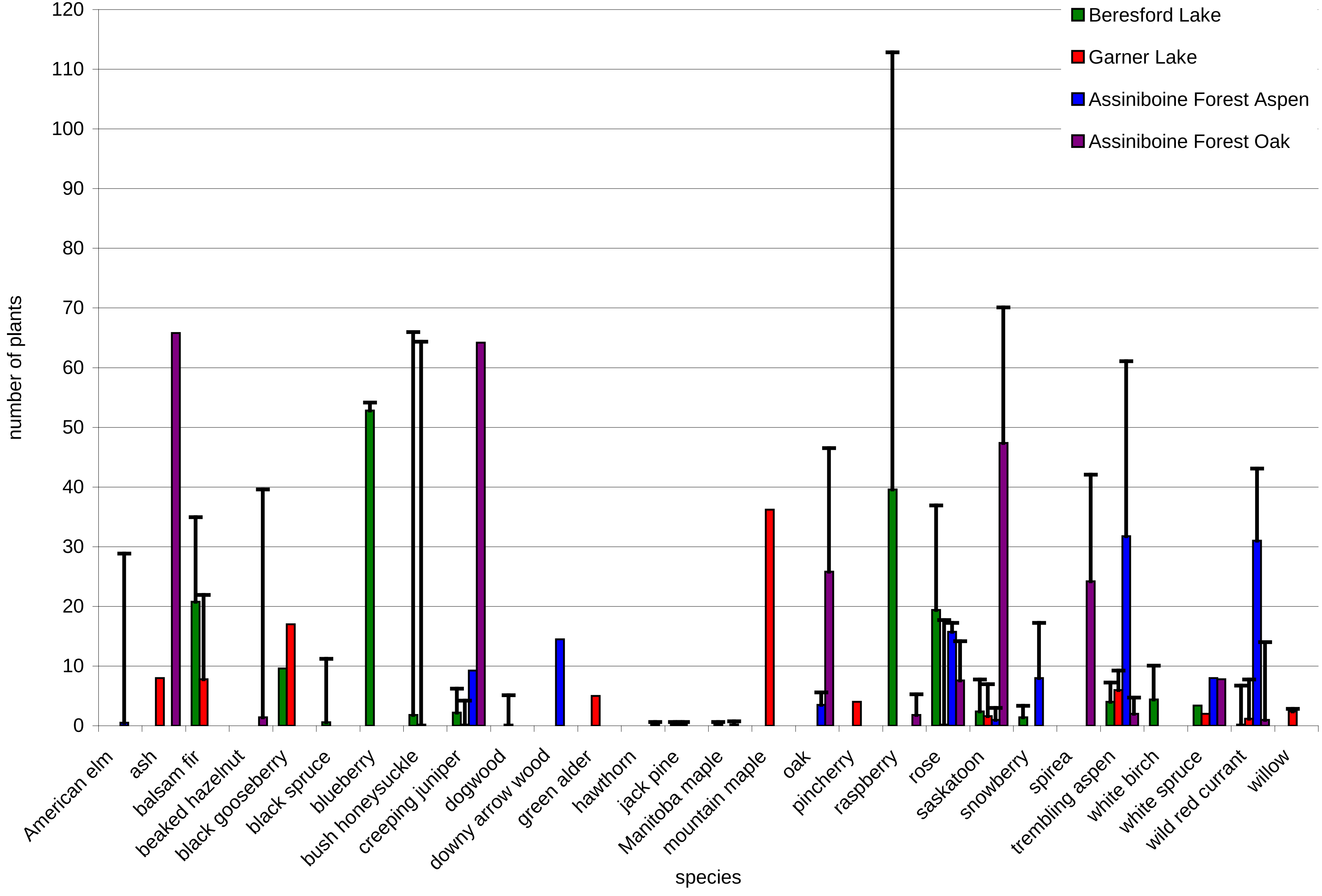


Figure 16. Average and standard deviation of each seedling and shrub species present in each quadrat for each forest type.

The oak plots had the greatest diversity of herbs present, 31 taxa. The Beresford Lake plots had 25 taxa, the aspen plots 26 taxa, and the Garner Lake plots 27 taxa (Fig. 17). Moss was the most abundant taxon in the boreal forest plots with an average percent cover of approximately 65%. In both the Beresford Lake and Garner Lake plots, *Cladina rangiferina* was the most abundant lichen, with a percent cover under 5% on average. The Beresford Lake plots also had *Cladina aruscula* while the Garner Lake plots also had *C. mitis* and *C. stellaris* as well as *Cladonia* species (Fig. 17). Grasses were the most abundant herbs in the Assiniboine Forest plots. Only the aspen plots had sedges and the aspen plots had a richer diversity of graminoids than the oak plots (Fig. 17).

When the 1 x m herb plot species list was combined with additional herb species noted in the 20x20 m plots, the Garner Lake plots had the richest diversity with 39 taxa (Table 1). The oak plots had 33 taxa, the Beresford Lake plots 30 taxa, and the aspen plots 29 taxa (Table 1).

The boreal forest plots were more variable than the Assiniboine Forest plots since they had more herbs that were not accounted for in the 1 x 1 m herb quadrats. The Garner Lake plots were very heterogeneous with 12 herbs present in the plots but absent from the quadrats. The Beresford Lake plots contained 5 such herbs. This in contrast to the oak plots with 2 and the aspen plots with 3 such herbs. The heterogeneity of the Garner Lake plots is emphasized by the lichen diversity present. *Cladonia* species are early successional species while *Cladina stellaris* is the slowest growing species of *Cladina* making it a late successional species that becomes established after the forest is nearly 100 years old. In the boreal forest, more than 5 plots may be required to capture the full variation present in the stands. In the urban forests, 5 plots are better able to capture the full diversity of herbs.

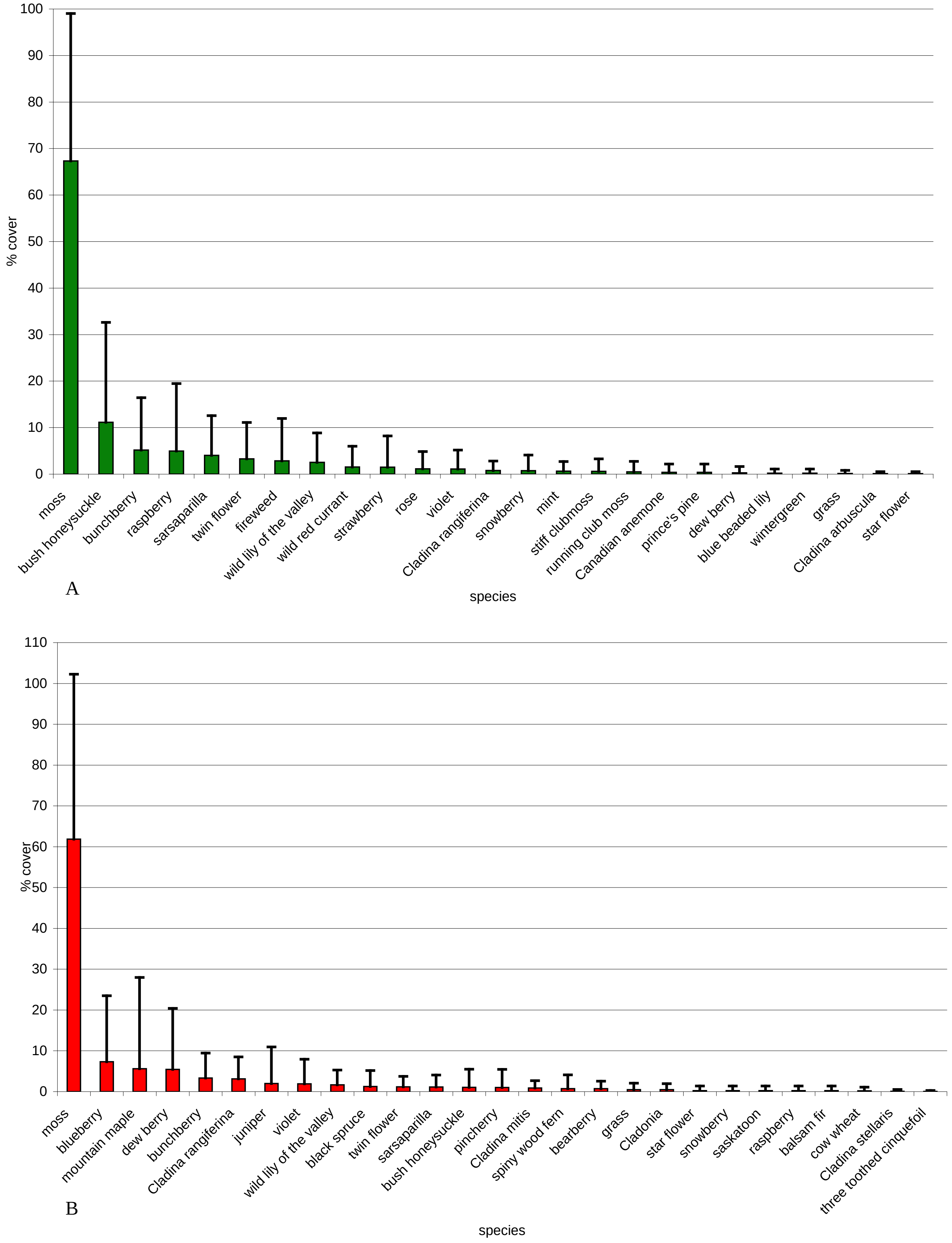
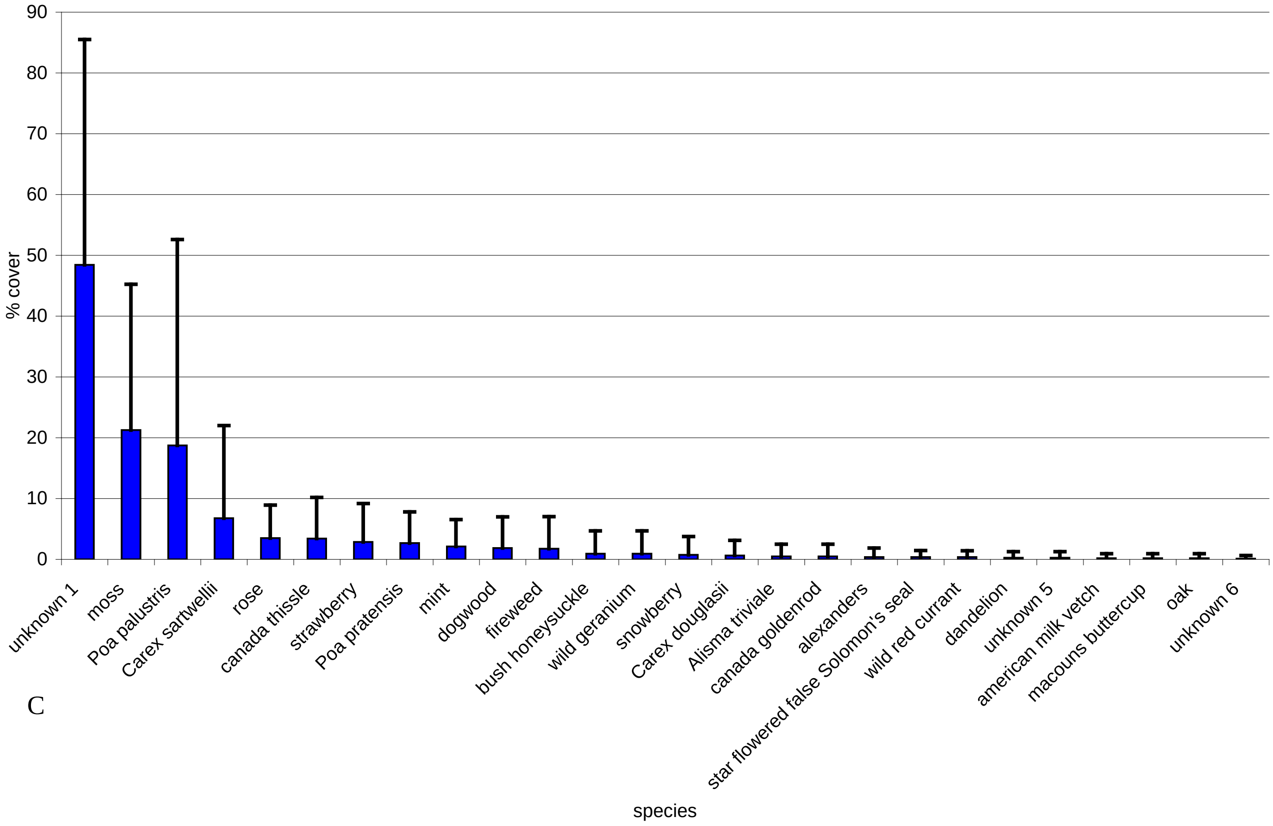


Figure 17. Average and standard deviations for the percent cover of each species in each herb plot for each of the forest types. A: Beresford Lake, B: Garner Lake, C: Assiniboine Forest aspen, D: Assiniboine Forest oak.



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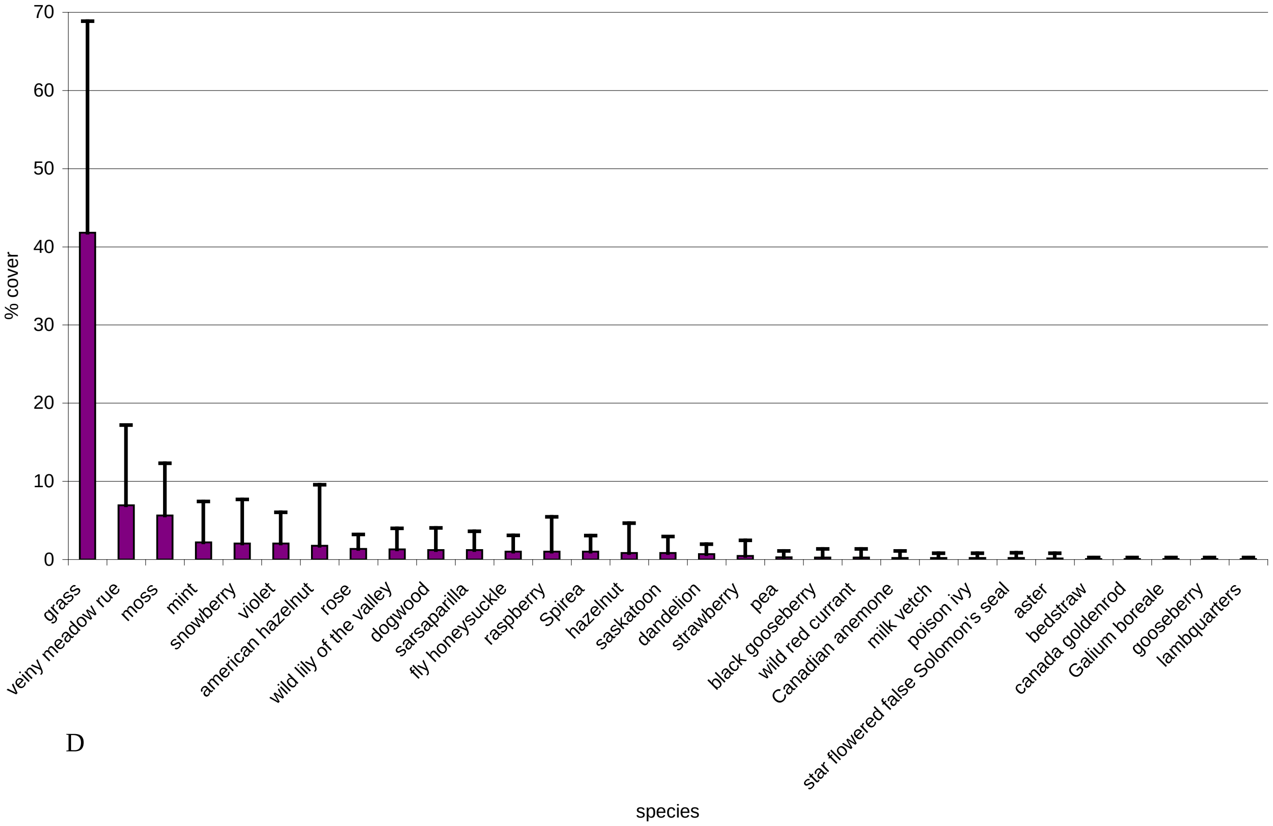

D

Figure 17 continued. Average and standard deviations for the percent cover of each species in each herb plot for each of the forest types. A: Beresford Lake, B: Garner Lake, C: Assiniboine Forest aspen, D: Assiniboine Forest oak.

There appears to be habitat differences between the two boreal forest plots as *Cladina arbuscula* was found in the Beresford Lake plots and *C. mitis* was found in the Garner Lake plots. The differences between these two species are subtle and are not recognized as separate species by all lichenologists. The difference in morphology is hypothesized to be due to different environmental conditions, a hypothesis supported by this data.

Table 1. The number of plots (five per forest type, four in the aspen plots) and the number of herb quadrats (25 per forest type, 20 in the aspen plots) in which each species was present. The additional species that were present in each plot are included in the number of plots in which the species was present but are not included in the number of quadrats in which the species was present.

	number of plots				number of quadrats			
species	Garner Lake	Beresford Lake	Assiniboine Forest, oak	Assiniboine Forest, aspen	Garner Lake	Beresford Lake	Assiniboine Forest, oak	Assiniboine Forest, aspen
alexanders (*Smyrnium* spp.)	not present	not present	not present	1	not present	not present	not present	1
Alisma triviale	not present	not present	not present	1	not present	not present	not present	1
American hazelnut (*Corylus cornuta*)	not present	not present	1	not present	not present	not present	1	not present
American milk vetch (*Astragalus americanus*)	not present	not present	2	1	not present	not present	2	1
aster (Asteraceae)	not present	not present	1	not present	not present	not present	1	not present
balsam fir (*Abies balsamea*)	1	not present	not present	not present	1	not present	not present	not present
bearberry (*Arctostaphylos uva-ursi*)	2	2	not present	not present	3	not present	not present	not present
bedstraw (*Galium vernum*)	not present	not present	1	not present	not present	not present	1	not present
bindweed *(Convolvulus* sp.)	1	not present	not present	not present	not present	not present	not present	not present
black gooseberry (*Ribes lacustre*)	not present	not present	1	not present	not present	not present	1	not present
black spruce (*Piceae mariana*)	2	not present	not present	not present	2	not present	not present	not present
blue beaded lily (*Clintonia borealis*)	3	1	not present	not present	not present	1	not present	not present
blueberry (*Vaccinium myrtilloides*)	4	3	not present	not present	5	not present	not present	not present
bunchberry (*Cornus canadensis*)	4	5	not present	not present	6	5	not present	not present
bush honeysuckle (*Dervilla lonicera*)	4	4	not present	1	2	8	not present	1
Calamagrostis canadensis	not present	not present	not present	2	not present	not present	not present	not present
Canada goldenrod (*Solidago canadensis*)	not present	not present	1	2	not present	not present	1	1
Canada thistle (*Cirsium arvense*)	not present	not present	not present	2	not present	not present	not present	4
Canadian anemone (*Anemone canadensis*)	not present	1	1	not present	not present	1	1	not present
Carex douglasii	not present	not present	not present	2	not present	not present	not present	1
Carex sartwellii	not present	not present	not present	3	not present	not present	not present	5
Cladina arbuscula	not present	2	not present	not present	not present	1	not present	not present
Cladina mitis	3	1	not present	not present	5	not present	not present	not present
Cladina rangiferina	4	3	not present	not present	9	3	not present	not present
Cladina stellaris	1	not present	not present	not present	1	not present	not present	not present
Cladonia	3	not present	not present	not present	3	not present	not present	not present
cow wheat (*Melampyrum lineare*)	1	not present	not present	not present	1	not present	not present	not present
dandelion (*Taraxicum officinale*)	not present	not present	5	1	not present	not present	6	1
dew berry (*Rubus pubescens*)	3	2	not present	not present	5	1	not present	not present

Table 1 continued	number of plots				number of quadrats			
species	Garner Lake	Beresford Lake	Assiniboine Forest, oak	Assiniboine Forest, aspen	Garner Lake	Beresford Lake	Assiniboine Forest, oak	Assiniboine Forest, aspen
dogwood (*Cornus* sp.)	not present	not present	4	1	not present	not present	6	2
fireweed (*Epilobum angustifolium*)	3	3	not present	1	not present	3	not present	2
fly honeysuckle (*Lonicera canadensis*)	not present	not present	2	not present	not present	not present	4	not present
Galium boreale	not present	not present	1	not present	not present	not present	1	not present
grass	2	1	5	not present	2	1	19	not present
indian pipe (*Monotropa uniflora*)	1	1	not present	not present	not present	not present	not present	not present
juniper (*Juniperus communis*)	1	not present	not present	not present	1	not present	not present	not present
labrador tea (*Ledum groenlandicum*)	1	not present	not present	not present	not present	not present	not present	not present
lambquarters (*Chenopodium album*)	not present	not present	1	not present	not present	not present	1	not present
macouns buttercup (*Ranunculus macounii*)	not present	not present	not present	1	not present	not present	not present	1
mint (*Mentha* spp.)	not present	2	4	4	not present	2	9	4
moccasin flower (*Cypripedium acaule*)	2	not present	not present	not present	not present	not present	not present	not present
moss	5	5	5	4	16	2not present	13	11
mountain maple (*Acer spicatum*)	1	not present	not present	not present	2	not present	not present	not present
oak (*Quercus macrocarpa*)	not present	not present	2	2	not present	not present	3	1
pea (Fabaceae)	not present	not present	3	not present	not present	not present	3	not present
Peltigera aphthosa	2	not present	not present	not present	not present	not present	not present	not present
pincherry (*Prunus pennsylvanica*)	1	not present	not present	not present	1	not present	not present	not present
Poa palustris	not present	not present	not present	2	not present	not present	not present	4
Poa pratensis	not present	not present	not present	2	not present	not present	not present	6
poison ivy (*Rhus toxicodendron*)	not present	not present	2	1	not present	not present	2	not present
prince's pine (*Chimaphila umbellata*)	3	3	not present	not present	not present	1	not present	not present
raspberry (*Rubus idaeus*)	3	3	1	not present	1	6	1	not present
rock polypody (*Polypodium virginianum*)	2	not present	not present	not present	not present	not present	not present	not present
rose (*Rosa acicularis*)	1	5	4	3	not present	2	9	6
running club moss (*Lycopodium* sp.)	not present	1	not present	not present	not present	1	not present	not present
sarsaparilla (*Aralia nudicaulis*)	5	4	3	not present	3	5	4	not present
saskatoon (*Amelanchier alnifolia*)	2	not present	3	not present	1	not present	3	not present
snowberry (*Gaultheria hispidula*)	1	1	2	2	1	1	6	1
spiny wood fern (*Dryopteris ausriaca*)	3	2	not present	not present	1	not present	not present	not present

Table 1 continued	number of plots				number of quadrats			
species	Garner Lake	Beresford Lake	Assiniboine Forest, oak	Assiniboine Forest, aspen	Garner Lake	Beresford Lake	Assiniboine Forest, oak	Assiniboine Forest, aspen
Spirea	not present	not present	3	not present	not present	not present	5	not present
spreading dogbane (*Apocynum androsaemifolium*)	not present	1	not present	not present	not present	not present	not present	not present
star flower (*Trientalis borealis*)	3	2	not present	1	1	1	not present	not present
false Solomon's seal (*Smilacina trifolia*)	1	not present	2	2	not present	not present	3	2
stiff clubmoss (*Lycopodium* sp.)	not present	1	not present	not present	not present	1	not present	not present
strawberry (*Fragaria vesca*)	1	3	2	3	not present	1	1	4
three toothed cinquefoil (*Potentilla tridentata*)	2	not present	not present	not present	1	not present	not present	not present
twin flower (*Linnaea borealis*)	5	5	not present	not present	5	4	not present	not present
unknown 1	not present	not present	not present	4	not present	not present	not present	14
unknown 5	not present	not present	not present	1	not present	not present	not present	1
unknown 6	not present	not present	not present	1	not present	not present	not present	1
veiny meadow rue (*Thanlictrum venulosum*)	not present	not present	5	not present	not present	not present	15	not present
violet (*Viola* spp.)	2	2	4	not present	3	2	7	not present
wild geranium (*Geranium maculatum*)	not present	not present	not present	1	not present	not present	not present	1
wild lily of the valley (*Maianthemum canadense*)	5	4	5	not present	7	4	6	not present
currant *(Ribes* sp.)	not present	2	1	3	not present	3	1	2
wintergreen (*Pyrola* spp.)	not present	2	not present	not present	not present	1	not present	not present
yarrow (*Achillia millefolium*)	not present	not present	2	not present	not present	not present	not present	not present

Light, Tree Height, Tree Age

The Garner Lake plots had the tallest trees, 19.7 metres, with the oak plots having the shortest trees, 7.9 metres (Table 2). The boreal forest plots had the oldest trees with ages greater than 100 years (Table 2). The age of the oak trees in the Assiniboine Forest was not assessed. The aspen plots had the lowest % light transmission with 14% reaching the ground, on average. The Garner Lake plots had the highest % transmission with 24% reaching the ground on average (Table 2). However, % light transmission was highly variable (Table 2).

Table 2. Average, ± standard deviation, of tree height, tree age, and percent light transmission in each of the forest types investigated.

site	tree height (m)	tree age (years)	% light transmission
Garner Lake	19.7±3.3	110.3±22.5	23.9±21.1
Beresfored Lake	17.4±2.5	135.4±9	18.2±18.3
Assiniboine Forest, oak	7.9±2.5		20.1±22.4
Assiniboine Forest, aspen	12.1±2.7	82.4±9.9	14±17.3

Woody Debris

The Beresford Lake plots had the greatest number of pieces of woody debris in each transect (Fig. 18) and the greatest volume of woody debris in each transect (Fig. 19). The Garner Lake plots had the next greatest volume and number of pieces followed by the oak plots and the aspen plots (Figs. 18 & 19).

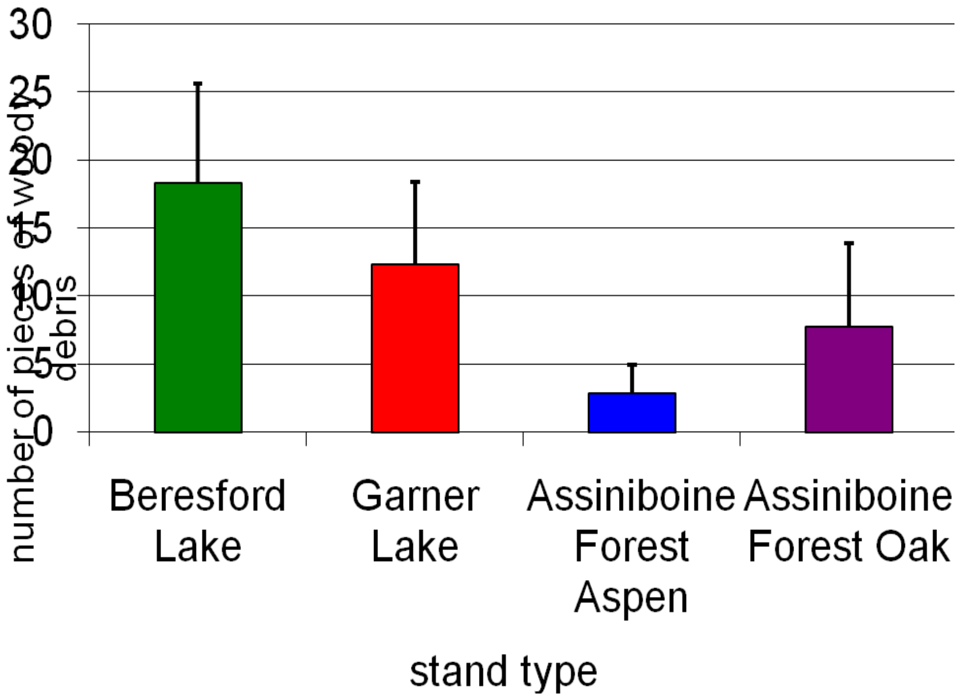

Figure 18. Number of downed woody debris per transect in the EMAN study plots.

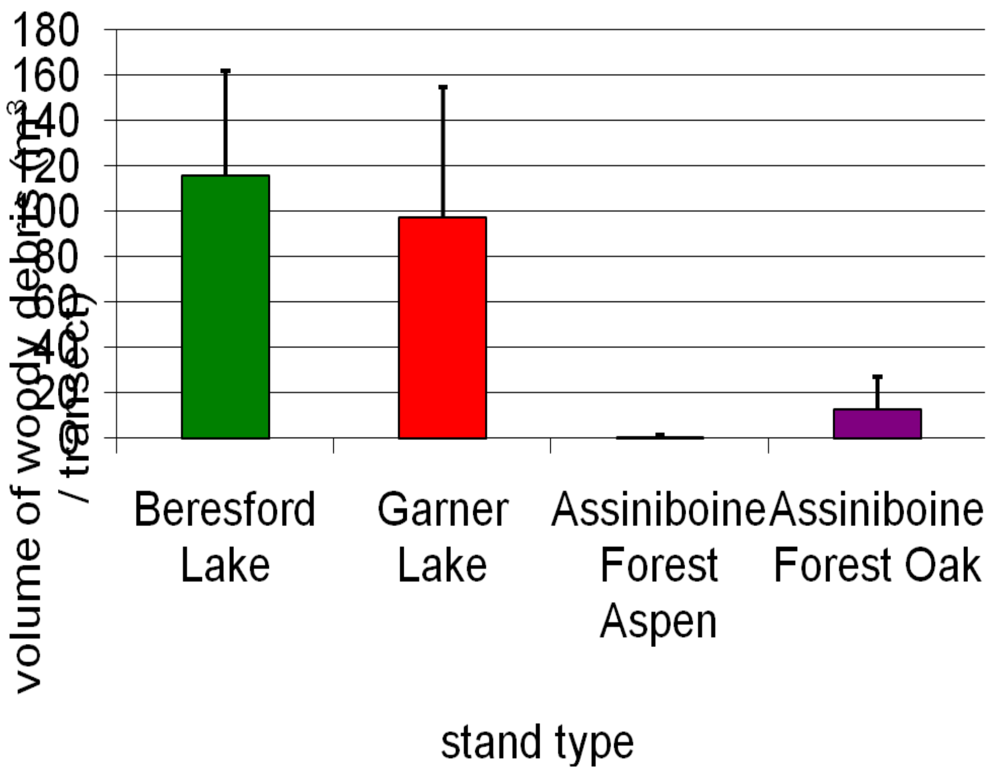

Figure 19. Volume (m3) of woody debris per transect in the EMAN study plots.

Most of the woody debris in the Beresford Lake plots was in either decomposition class 2 or 3. In the Garner Lake plots, it was mostly decomposition class 1 while in the aspen plots it was mostly class 3 and mostly class 4 in the oak plots (Fig. 20). There were no recently fallen trees, decomposition class 1 or 2, in the Assiniboine Forest aspen plots, while all five classes were present in the other forest types (Fig. 20).

With over 60% of the woody debris in class 3 in the aspen plots, it appears that there was one episode in which the trees fell. The woody debris in the oak plots is also mostly older debris indicating that conditions may have been different in these plots in the past to allow for more woody debris. On the other hand, the boreal plots had more class 1, 2, and 3 woody debris than class 4 and 5 indicating that trees fall more regularly than in the urban forest, with likely several more recent episodes of falling trees in the recent past.

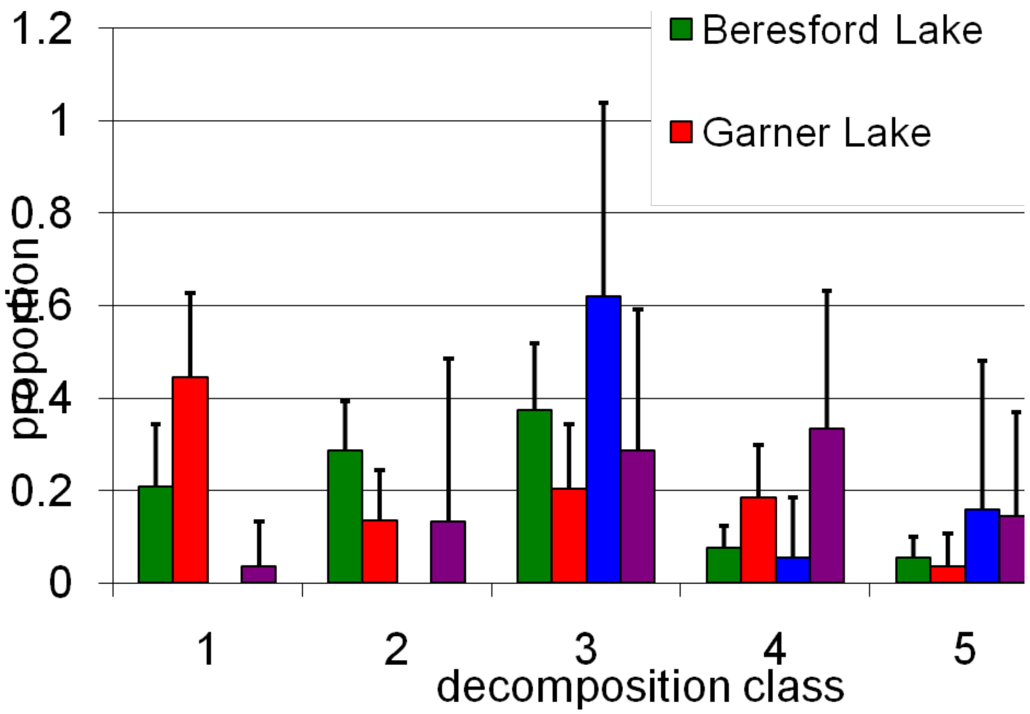

Figure 20. Proportion of downed woody debris in each decomposition class for the EMAN study plots.

Riparian Transects

The practice of leaving forested riparian buffer strips following logging is common worldwide. Forested buffers are reported to protect water quality by filtering the water before it enters a water body and to anchor the soil to prevent erosion. These buffers also provide habitat for unique riparian vegetation and wildlife and provides for animal travel corridors. Forest buffers can also be used to increase aesthetics of an area by concealing harvested areas. Furthermore, they minimise sedimentation due to soil exposure, maintain bank stability, and provide coarse wood y debris for stream structure.

However, there may also be disadvantages associated with these buffers. They create artificial strips of trees along water bodies, patterns that do not occur naturally. There is also an increased risk of insects and disease in the buffers strips. Furthermore, there is an inability to manage these areas after logging operations have left the area and roads have been decommissioned. Also of concern is the ability of these trees to persist in a healthy and standing position once the surrounding forest has been cleared. Without the protection of surrounding trees following logging, there is no longer sufficient protection for the trees from the wind, and so they could rapidly blow down.

Following clear cutting, the wind is deflected up over the canopy as well as into the canopy (Steil et al 2005). This increases the velocity of the wind because the frictional boundary which was above the canopy has been moved to ground level. The wind remains at an elevated velocity for several tree lengths in to the forest, possibly representing a significant proportion of the width of a 100 metre buffer. Clear cutting exposes trees to edge effects that were not previously exposed to edge effects and so as these trees are not physiologically adapted to their new environment, and thus they are susceptible to being blown over in weaker winds than would have been required for the trees in the edge environments preceding the harvest (Steil et al 2005).

In our study, we established 100 m long line transects along shorelines, 50 m inland from shorelines and 100 m from shorelines on lakes that either did or did not experience adjacent upland forest harvesting. The transects were located on east, west, north and south shorelines (Table 3).

Table 3. Number of transects on each side of the lake for the riparian data collected.

Side of Lake	Lake shore		50 m from lake shore		100 m from lake shore	
	Control	Harvest	Control	Harvest	Control	Harvest
North	3	4	2	5	2	5
East	4	5	3	5	1	5
South	4	2	4	2	4	2
West	2	6	1	4	1	6

Our data collected along transects on lakeshores and cut block edges on lakes in which adjacent upland harvest occurred indicates that significant blow-down of trees can occur. When not considering the location (east, south, west, north) on a lake, there was a significantly higher proportion of the riparian width blown down around lakes which had experienced forest harvesting than around lakes without adjacent forest harvesting (Fig, 21). On average, 33% of the buffer width was blown down along shorelines of lakes with harvesting (compared to 10% in reference lakes) and 40% of the buffer width was blown down at the cub block/riparian forest edge (compared to 9% for reference lakes). It also appeared that there was more blow down along the cut block-riparian forest edge than along the lake-riparian forest edge (Fig. 21). This might be due to the fact that riparian forest growing along a water body may be more adapted to wind events compared to forests further inland which have been protected by the wind by surrounding trees.

Figure 21. Proportion of 100 m buffer width in blown down condition in lakeshore transects (A) and buffer/cut block boundary transects (C), around lakes with and without forest harvesting.

The location around a lake (east, west, north, south) did not appear to have any consistent influence on the proportion of buffer width blow down (Fig. 22 a & b). For example, a higher proportion of blow down width around lakes with forest harvesting occurred on south and west shores along the lake shores (Fig. 22a) but was higher along north and west shores at the cut block/riparian forest boundary (Fig. 22b). However, it was evident that the proportion of blow down width was much higher at both lakeshore and cut block/riparian forest boundary transects around lakes with forest harvesting than around lakes without harvesting. There was one transect that did not conform to this finding. A transect 100 m from shore on the west shore of Key Lake had 75% blow down (Fig. 22b). This unfortunately was our only transect on a west shore, 100 m from shore and around a control (reference) lake. Therefore, the sample size for this particular site type (i.e., control lake, 100 m from shore, west shore) was very limited (i.e., n=1).

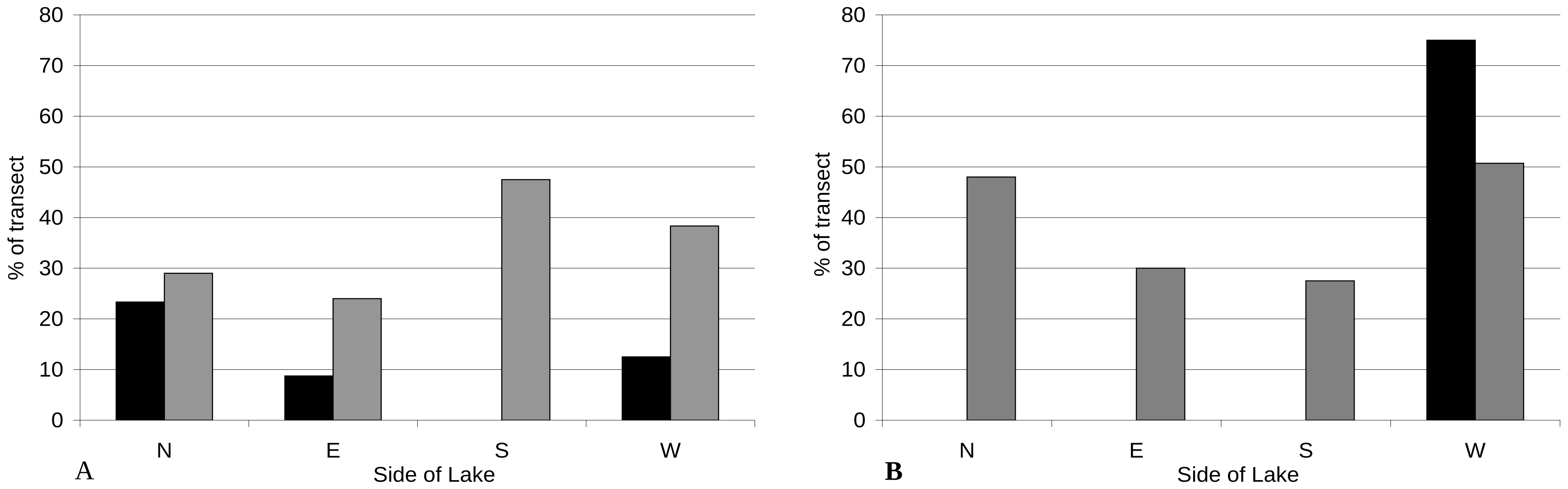

Figure 22. Average maximum percentage of trasects blown down. Black bars: control, grey bars: harvest. A: transects at shoreline. B: transects 100 metres from shore.

Fig. 23 provides two photographs of one of the cutblock boundary (100 m from lakeshore) transects on Metcalf Lake, a lake in which adjacent upland forest harvesting occurred.

Figure 23. Examples of blow-down in riparian forests along a cutblock boundary at Metcalf Lake.

Overall, alive leaning and fallen trees made up a small proportion of the total trees in each transect (Fig. 24). Control transects on the east side of the lakes had a greater proportion of alive leaning and fallen trees than did the transects adjacent to the harvested areas. On all other sides of the lakes, the transects by the cut blocks had a greater proportion of alive leaning and fallen trees (Fig. 24). The abundance of trees in decomposition classes greater than 2 indicates that there was a stormy period in the past in which many trees were blown down. The lack of consistency with either the controls or buffers having a greater proportion of trees in any lean/fall category indicates a certain degree of randomness as to which set of transects had the greater proportion. The proportion of trees in each of the three lean/fall categories was fairly similar on all sides of the lakes with there not really being one side of the lakes being unique.

On all sides of the lakes in all transects, on average, there was a greater proportion of trees in decomposition classes 3 through 5 than dead leaning trees and fallen trees in decomposition classes 1 and 2. There were three exceptions to this, namely the control transects on the south side of the lakes 50 metres from the lake shore and the harvest transects on the north and south shores of the lakes at the cut blocks (Fig. 24). There was little consistency as to whether the control transects or the buffers had a greater proportion of trees in each category. On the north and west sides of the lakes, the buffer strips had more trees in the alive leaning and alive fallen category than the control transects though the controls had more on the east side of the lakes (Fig. 24). There was no clear trend for the dead leaning and recently fallen dead trees (Fig. 24).

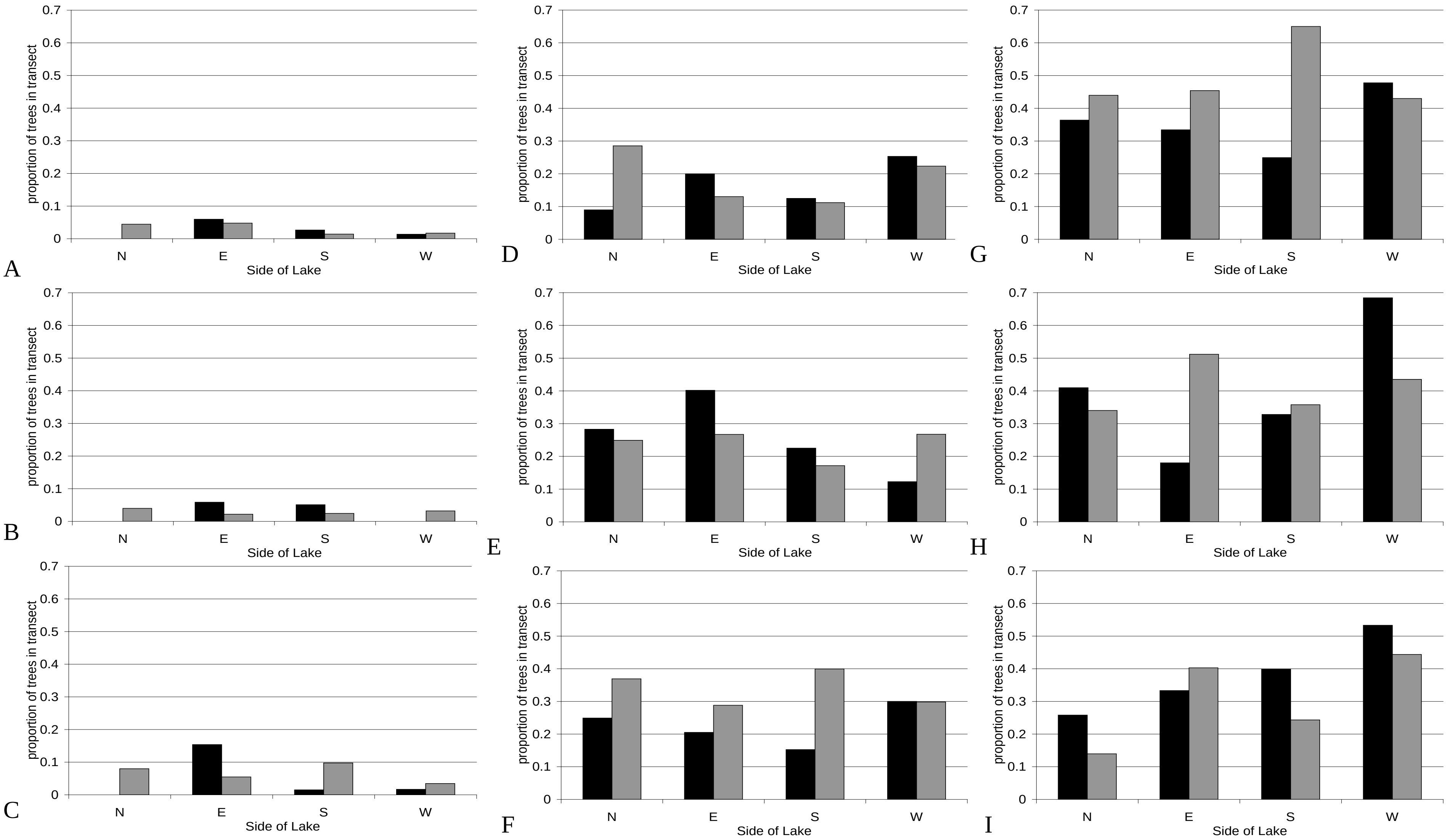

Figure 24. Average proportion of trees in the transects that were leaning or fallen. Black bars: control transects, grey bars: harvest transects. A,D,G: lakeshore transects, B,E,H: trasnects 50 metres from lake shore, C,F,I: transects 100 metres from lake shore. A,B,C: alive leaning and alive fallen trees, D,E,F: deaf leaning trees and dead fallen trees in class 1 and 2, G,H,I: dead leaning tres in classs 3,4, and 5.

For the old fallen trees, class 3 through 5, the controls had a greater proportion than the buffers on the north and west sides of the lakes, though the opposite was true on the east sides of the lakes (Fig. 24). Very often the differences between controls and buffers were not very great and the trends were not consistent even with in a single category of trees or across categories of trees (Fig. 24).

The predominance of trees fallen to the east is due to the prevailing winds being the westerlies, which also accounts for the lack of trees fallen to the west. The lack of a clear trend of the trees in the controls or buffers falling in different directions indicates a certain degree of chance as to which direction a tree will actually fall, with the probabilities of a tree falling in a certain direction being the same for the transects in both the controls and buffers.

As to which direction the trees were leaning or fallen in, the majority of trees were pointing to the east with the fewest trees pointing to the west (Fig. 25). Again there were no clear trends as to whether the trees in the controls or buffers had a tendency to prefer different direction of tilt.

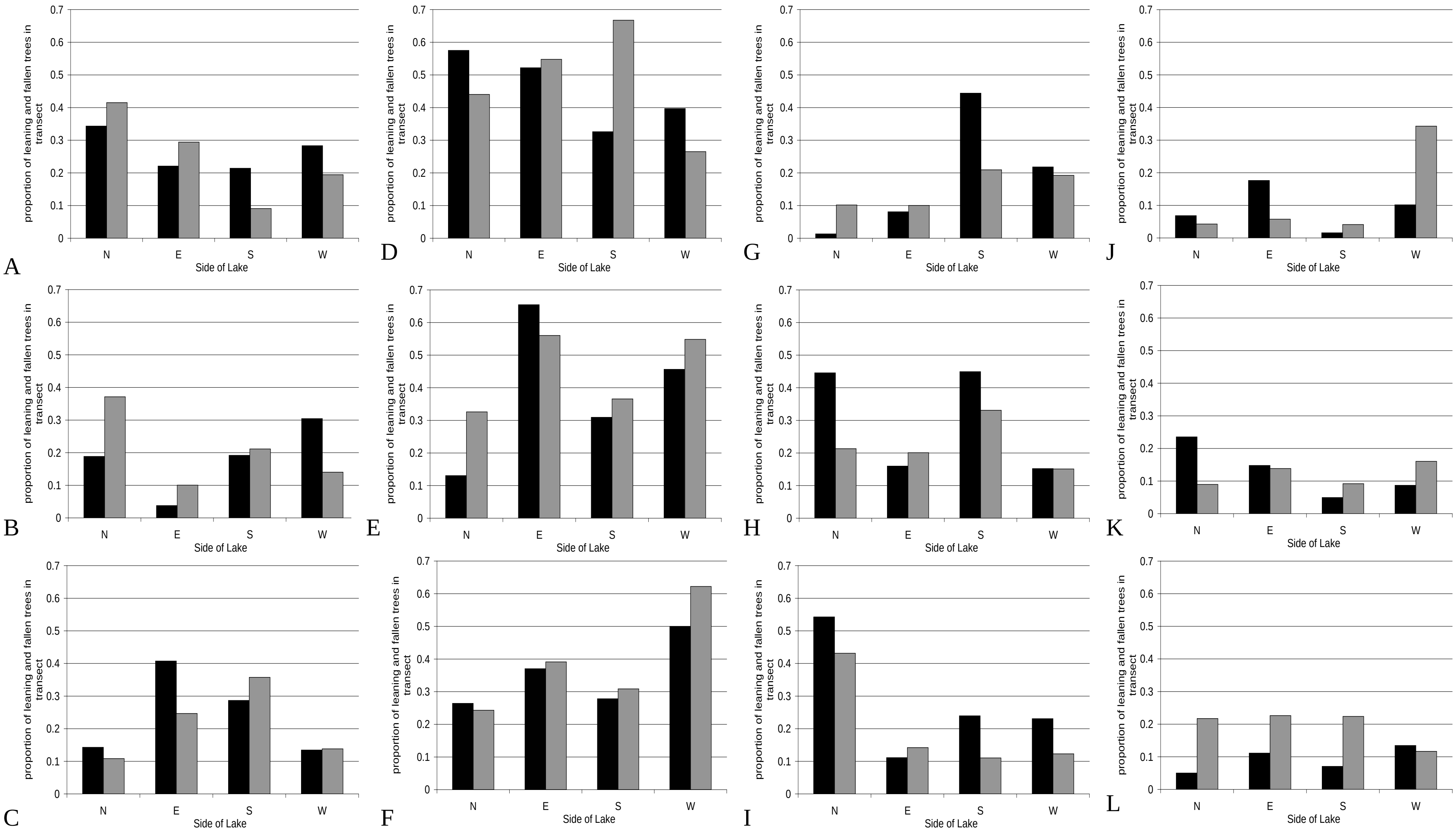

Figure 25. Average proportion of leaning and fallen trees in each transect that were leaning/fallen in each cardinal direction. Black bars: control transects, grey bars: harvest transects. A,D,G,L: lake shore transects, B,E,H,K: transects 50 metres from lake shore, C, F, I, L: transects 100 metres from lake shore. A,B,C: trees pointing to the North, D,E,F: trees pointing to the East, G,H,I: trees pointing to the South, J,K,L: trees pointing to the West.

Open and closed wounds along with wet and dry frost cracks were the most common defects with the closed wounds being the most abundant defect (Fig. 26). Generally the trees in the control transects had more defects than the trees in the buffers (Fig. 26). This is likely due to there being a greater number of trees standing in the control transects than in the buffers.

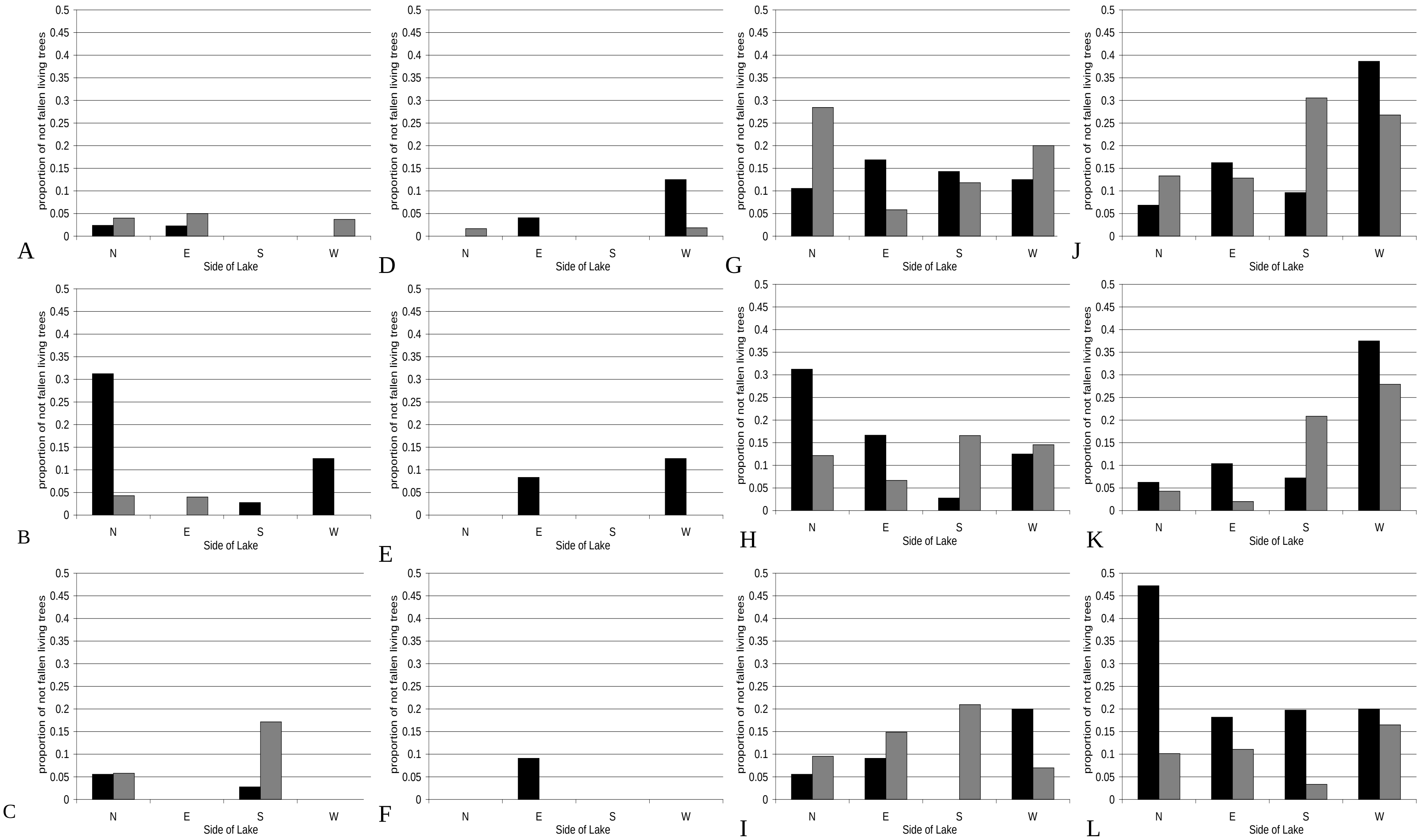

Figure 26. Average proportion of alive, not fallen, trees with the most common defects. Black bars: control transects, grey bars: harvest transects. A,D,G,J: lake shore transects, B,E,H,K: transects 50 metres from the lake shore, C,F,I,L: transects 100 metres from the lake shore. A,B,C: trees with dry frost cracks, D,E,F: trees with wet frost cracks, G,H,I: tres with open wounds, J,K,L: trees with closed wounds.

The fallen and leaning trees in the control transects were not more or less frequent than in the buffers strips though they were just isolated trees while in the buffer strips entire swathes of the forest were blown down, both at the cut block and at the lake shore. The most extreme instances having blown down the entire 100 metre buffer strip.

Our study does indicate that there is an increased incidence of blow down, particularly the maximum width of blow down in both lake shore and cut block/riparian forest edge locations following forest harvesting. In order to better understand his phenomenon, we recommend that EMAN-type plots be established in riparian areas around lakes prior to forest harvesting, in order to follow changes in vegetation attributes following harvesting.

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Appendix A. Coordinates of the A post for each EMAN plot established.

Forest type	Plot	Latitude (N dd mm.mmm)	Longitude (W dd mm.mmm)	Accuracy (m)	Bearing (deg)
Beresford Lake	1	50 52.570	95 13.675	7	30
Beresford Lake	2	50 52.487	95 13.684	8	70
Beresford Lake	3	50 52.402	95 13.813	7	90
Beresford Lake	4	50 52.323	95 13.825	4	90
Beresford Lake	5	50 52.251	95 13.835	4	90
Garner Lake	1	50 48.680	95 09.578	6	90
Garner Lake	2	50 48.638	95 09.630	8	140
Garner Lake	3	50 48.616	95 9.676	6	140
Garner Lake	4	50 48.594	95 9.757	8	140
Garner Lake	5	50 48.565	95 9.820	8	140
Assiniboine Forest aspen	1	49 51.449	97 14.852	6	270
Assiniboine Forest aspen	2	49 51.465	97 14.833	6	0
Assiniboine Forest aspen	3	49 50.888	97 14.868	12	150
Assiniboine Forest aspen	4	49 50.870	97 14.843	19	150
Assiniboine Forest aspen	5				
Assiniboine Forest oak	1	49 51.335	97 14.534	2	180
Assiniboine Forest oak	2	49 51.346	97 14.508	5	0
Assiniboine Forest oak	3	49 51.371	97 14.497	3	0
Assiniboine Forest oak	4	49 51.353	97 14.577	7	180
Assiniboine Forest oak	5	49 51.367	97 14.563	8	0

Appendix B. Coordinates for each Riparian Transect established.

Lake	Transect	ABC	Side of Lake	Harvest/ Control	Starting Latitude (dd mm.mmm)	Starting Longitude (dd mm.mmm)	Accuracy (m)	Finishing Latitude (dd mm.mmm)	Finishing Longitude (dd mm.mmm)	Accuracy (m)
Key	1	A	W	H	N50 31.931	W95 25.483	±4	N50 31.900	W95 25.429	±8
Key	1	C	W	H	N50 31.895	W95 25.533	±6	N50 31.848	W95 25.491	±9
Key	2	A	W	H	N50 31.870	W95 25.399	±11	N50 31.825	W95 25.412	±8
Key	2	C	W	H	N50 31.842	W95 25.476	±5	N50 31.795	W95 25.453	±11
Key	3	A	W	C	N50 31.834	W95 25.264	±2	N50 31.807	W95 25.202	±5
Key	3	B	W	C	N50 31.789	W95 25.222	±5	N50 31.757	W05 25.304	±15
Key	3	C	W	C	N50 31.758	W95 25.317	±9	N50 31.712	W95 25.336	±13
Key	4	A	W	C	N50 31.781	W95 25.169	±7	N50 31.759	W95 25.237	±8
Lapin	1	A	W	H	N50 32.153	W95 22.359	±7	N50 32.198	W95 22.374	±9
Lapin	1	B	W	H	N50 32.176	W95 22.418	±9	N50 32.221	W95 22.393	±11
Lapin	1	C	W	H	N50 32.196	W95 22.470	±7	N50 32.235	W95 22.429	±12
Lapin	2	A	W	H	N50 32.232	W95 22.346	±10	N50 32.268	W95 22.294	±12
Lapin	2	B	W	H	N50 32.234	W95 22.384	±7	N50 32.278	W95 22.328	±9
Lapin	2	C	W	H	N50 32.246	W95 22.417	±5	N50 32.294	W95 22.392	±6
Lower Lazy Lake	1	A	N	C	N50 32.265	W95 22.967	±6	N50 32.237	W95 22.885	±9
Lower Lazy Lake	1	B	N	C	N50 32.287	W95 22.935	±8	N50 32.278	W95 22.870	±7
Lower Lazy Lake	1	C	N	C	N50 32.322	W95 22.921	±7	N50 32.284	W95 22.892	±7
Lower Lazy Lake	2	A	E	H	N50 32.246	W95 22.785	±6	N50 32.221	W95 22.745	±9
Lower Lazy Lake	2	B	E	H	N50 32.280	W95 22.774	±4	N50 32.247	W95 22.708	±6
Lower Lazy Lake	2	C	E	H	N50 32.306	W95 22,745	±6	N50 32.275	W95 22.695	±7
Lower Lazy Lake	3	A	E	H	N50 32.193	W95 22.685	±6	N50 32.150	W95 22.645	±12
Lower Lazy Lake	3	B	E	H	N50 32.205	W95 22.652	±4	N50 32.161	W95 22.606	±13
Lower Lazy Lake	3	C	E	H	N50 32.223	W95 22.627	±8	N50 32.179	W95 22.580	±9
Metcalf	1	A	W	H	N50 32.395	W95 24.811	±6	N50 32.442	W95 24.825	±6
Metcalf	1	B	W	H	N50 32.390	W95 24.847	±6	N50 32.444	W95 24.863	±5
Metcalf	1	C	W	H	N50 32.395	W95 24.887	±10	N50 32.444	W95 24.896	±8
Metcalf	2	A	S	H	N50 32.567	W95 24.928	±6	N50 32.547	W95 25.004	±5
Metcalf	2	B	S	H	N50 32.525	W95 24.921	±8	N50 32.509	W95 25.001	±9
Metcalf	2	C	S	H	N50 32.492	W95 24.996	±11	N50 32.478	W95 24.929	±9

Metcalf	3	A	S	H	N50 32.541	W95 25.058	±12	N50 32.503	W95 25.127	±12
Metcalf	3	B	S	H	N50 32.458	W95 25.116	±5	N50 32.511	W95 25.066	±13
Metcalf	3	C	S	H	N50 32.484	W95 25.041	±5	N50 32.453	W95 25.098	±9
Metcalf	4	A	W	H	N50 32.555	W95 25.256	±12	N50 32.595	W95 25.291	±8
Metcalf	4	B	W	H	N50 32.549	W95 25.299	±16	N50 32.597	W95 25.316	±6
Metcalf	4	C	W	H	N50 32.547	W95 25 334	±6	N50 32.604	W95 25.334	±14
Metcalf	5	A	N	H	N50 32.640	W95 24.936	±8	N50 32.645	W95 24.865	±12
Metcalf	5	B	N	H	N50 32.665	W95 24.954	±12	N50 32.677	W95 24.869	±13
Metcalf	5	C	N	H	N50 32.691	W95 24.949	±10	N50 32.697	W95 24 868	±13
Metcalf	6	A	N	H	N50 32.613	W95 24.724	±8	N50 32.607	W95 24.642	±11
Metcalf	6	B	N	H	N50 32.643	W95 24.704	±7	N50 32.644	W95 24.6.24	±8
Metcalf	6	C	N	H	N50 32.667	W95 24.685	±6	N50 32.664	W95 24.608	±6
Metcalf	7	A	N	H	N50 32.591	W95 24.401	±4	N50 32.579	W95 24.324	±8
Metcalf	7	B	N	H	N50 32.617	W95 24.409	±5	N50 32.595	W95 24.338	±10
Metcalf	7	C	N	H	N50 32.653	W95 24.399	±6	N50 32.630	W95 24.324	±15
Metcalf	8	A	E	H	N50 32.569	W95 24.253	±9	N50 32.533	W95 24.210	±7
Metcalf	8	B	E	H	N50 32.579	W95 24.210	±7	N50 32.536	W95 24.184	±13
Metcalf	8	C	E	H	N50 32.598	W95 24.161	±7	N50 32.553	W95 24.147	±5
Running Pine Lake	1	A	E	C	N50 30.254	W95 24.072	±7	N50 30.208	W95 24.044	±9
Running Pine Lake	1	B	E	C	N50 30.125	W95 23.912	±6	N50 30.180	W95 23.927	±11
Running Pine Lake	2	A	E	C	N50 30.187	W95 24.092	±13	N50 30.141	W95 24.045	±12
Running Pine Lake	3	A	N	C	N50 30.051	W95 23.914	±10	N50 30.066	W95 23.878	±5
Running Pine Lake	3	B	N	C	N50 30.090	W95 23.909	±6	N50 30.081	W95 23.833	±6
Running Pine Lake	3	C	N	C	N50 30.209	W95 23.908	±6	N50 30.196	W95 23.841	±6
Running Pine Lake	4	A	N	C	N50 30.035	W95 23.775	±14	N50 30.028	W95 23.717	±10
Running Pine Lake	5	A	E	H	N50 30.256	W95 23.094	±9	N50 30.311	W95 23.055	±6
Running Pine Lake	5	B	E	H	N50 30.253	W95 23.059	±9	N50 30.302	W95 23.036	±9
Running Pine Lake	5	C	E	H	N50 30.255	W95 23.015	±11	N50 30.302	W95 23.001	±7
Running Pine Lake	6	A	E	H	N50 30.146	W95 23.139	±10	N50 30.191	W95 23.126	±11
Running Pine Lake	6	B	E	H	N50 30.144	W95 23.084	±18	N50 30.197	W95 23.074	±14
Running Pine Lake	6	C	E	H	N50 30.138	W95 23.027	±13	N50 30.186	W95 23.026	±12

Running Pine Lake	7	A	N	H	N50 29.999	W95 22.948	±11	N50 30.025	W95 23.013	±8
Running Pine Lake	7	B	N	H	N50 30.024	W95 22.938	±9	N50 30.029	W95 23.053	±10
Running Pine Lake	7	C	N	H	N50 30.052	W95 22.924	±11	N50 30.070	W95 22.997	±9
Running Pine Lake	8	A	N	H	N50 29.963	W95 22.814	±8	N50 29.982	W95 22.873	±17
Running Pine Lake	8	B	N	H	N50 29.989	W95 22.803	±7	N50 30.012	W95 22.870	±12
Running Pine Lake	8	C	N	H	N50 30.014	W95 22.790	±8	N50 30.043	W95 22.850	±8
Running Pine Lake	9	A	S	C	N50 29.935	W95 23.060	±3	N50 29.933	W95 23.145	±9
Running Pine Lake	9	B	S	C	N50 29.906	W95 23.069	±12	N50 29.912	W95 23.139	±15
Running Pine Lake	9	C	S	C	N50 29.660	W95 23.250	±17	N50 29.687	W95 23.278	±9
Running Pine Lake	10	A	S	C	N50 29.959	W95 23.200	±8	N50 29.947	W95 23.279	±14
Running Pine Lake	10	B	S	C	N50 29.923	W95 23.215	±6	N50.29.916	W95 23.308	±12
Running Pine Lake	10	C	S	C	N50 29.783	W95 23.337	±12	N50 29.806	W95 23.381	±8
Running Pine Lake	11	A	S	C	N50 29.972	W95 23.632	±10	N50 29.952	W95 23. 719	±6
Running Pine Lake	11	B	S	C	N50 29.941	W95 23.637	±6	N50 29.935	W95 23.721	±7
Running Pine Lake	11	C	S	C	N50 29.928	W95 23.689	±8	N50 29.937	W95 23.748	±7
Running Pine Lake	12	A	S	C	N50 29.952	W95 24.019	±9	N50 29.953	W95 24.093	±10
Running Pine Lake	12	B	S	C	N50 29.917	W95 24.019	±11	N50 29.915	W95 24.105	±8
Running Pine Lake	12	C	S	C	N50 29.914	W95 24.021	±9	N50 29.897	W95 24.108	±12
Upper Lazy Lake	1	A	E	C	N50 32.533	W95 23.132	±9	N50 32.496	W95 23.167	±7
Upper Lazy Lake	1	B	E	C	N50 32.524	W95 23.089	±5	N50 32.479	W95 23.050	±8
Upper Lazy Lake	1	C	E	C	N50 32.451	W95 22.863	±12	N50 32.438	W95 22.923	±14
Upper Lazy Lake	2	A	E	C	N50 32.436	W95 23.153	±11	N50 32.392	W95 23.154	±12
Upper Lazy Lake	2	B	E	C	N50 32.420	W95 23.114	±6	N50 32.374	W95 23.139	±6